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Welding in Nuclear Engineering

THE art of welding has made rapid advances in the past 30 years and although new processes are constantly being developed and new problems constantly overcome, few metals or combinations of metals remain which cannot be joined successfully (although there are many combinations which a wise designer would not contemplate).

In view of the tremendous strides that have been made, it is perhaps surprising that the development of automatic welding processes, particularly for site work, has proceeded so slowly. There is still a tradition that mild steel is welded by hand and designers of special plant have, in the main, been reluctant to proceed with the design of automatic welding equipment as an integral part of that design. It seems reasonable to expect the designer of, say, a large circular pressure vessel to contemplate from the outset the construction of an automatic machine to do the fabrication and, where necessary, adapt his vessel design so that the automatic welding is simplified.

There are, of course, still sceptics who believe that an automatic machine (except possibly for simple downhand welds) will not produce the same quality weld as a first-class welder. This ignores the fact that the first-class welder is not always doing his best work and it is much more difficult to be sure that only the correct electrodes are always used and, for example, in the case of low hydrogen electrodes that these are maintained in the necessary dry condition. It is now common practice for the boilers for the civil reactors to be seam and circumferentially welded by automatic machines and elegant flame cutting equipment has been developed for cutting the holes for oblique nozzles; there are too on the market, machines capable of doing vertical and horizontal seam welds. It would still seem, however, that there is a great deal of room for the development of special purpose machines for the automatic welding of large vessels and ducts.

A new technique that was evolved in Russia, which at first seemed to have considerable scope in the nuclear field, was the electro-slag process, but doubts have been raised as to the ductility of the joints so produced and the Russians themselves have begun to introduce post-welding heat treatment in order to refine the grain structure. If such techniques can be made as simple and as effective as the welding process itself, then electro-slag welding may yet assume a significant place in pressure vessel construction for both shop and site fabrication.

The rapid growth of shielded arc processes has been of the greatest importance in fuel element manufacture. Although, when something goes wrong in the process, the number of rejects can be high, the number which escape detection in the test procedures and subsequently fail in the reactor due to defects (we are thinking here of Calder Hall cans) is small indeed. Ultimately it may be possible to simplify the inspection procedure with consequent economic advantages, but the big problem is testing the finished product—which can only be by irradiation in a reactor—and with the low statistical failure rate that is aimed at this process must take a long time.

Investigation of the improvements in methods of sealing magnox cans is one of the tasks that is being handled by the British Welding Research Association. The Association, which is largely financed by its member companies, has grown considerably in the 15 years since it first began operation in old Army huts at Abingdon Hall, near Cambridge. The establishment has grown out of all recognition and its present international reputation is enviable. It is instructive to note how much of the work of the Association is concerned with design considerations as distinct from the simple act of joining. It does carry out fundamental research into the physics of welding arcs, it is concerned with the development of new welding processes such as the consumable electrode welding of zirconium and it is continually solving specific problems posed by its members and giving advice and instruction, but a great deal of effort is expended on the improvement of design. This could be seen from the dominant part played by the Association in the Institute of Mechanical Engineers Symposium in January on Pressure Vessel Research Towards Better Design (*Nuclear Engineering*, March, p. 123). BWRA has its own programme of work on fatigue and brittle fracture and for this last has built a delightfully simple stressing machine designed to strain large welded plates in the direction of the weld and at a temperature that can be controlled. An important aspect of its research also is the correlation of defects with material performance, a subject that has been sadly neglected elsewhere.

The Association is able to provide convincing demonstration of the importance of design in any welded joint and is conscious of the scarcity in this country of what might be called welding engineers, i.e., design engineers with a real knowledge of welding. This is in marked contrast to the situation in Russia where great emphasis is placed on the training of engineers who have been given a thorough grounding in welding techniques and the implications of welding procedures and where welding is a subject included in most engineering training courses.

There is no doubt that, particularly in pressure circuits, the conservative attitude of many of the insurance companies and the outdated nature of the codes are major deterrents to design improvement. Nuclear engineering is more fortunate in this respect than the older industries as designers, customers and assessors are on the whole progressively minded. Nevertheless revision is necessary and we are pleased to see that Dr. Carlson has been continuing his crusade for an internationally acceptable code, before the International Institute of Welding at its meeting in N.Y. We should like to think that the deliberations of this body will be given the active study that they merit. In the main, the joining techniques are available; it is designers and insurers who lag.

Industrial Changes

YET another name must be deleted from the list of nuclear engineering companies. The Hawker Siddeley Group has decided to shut down its Nuclear Power Company and the works and laboratories at Langley. The company was first formed in January, 1956 with the specific aim of developing reactor systems for special applications. Over the years its activities have become somewhat diversified but the central purpose of the company was reactor development with a particular eye on the research field, marine propulsion and aircraft propulsion. Hawker Siddeley were the first company in this country to develop a low power research reactor, proceeding from the basic Argonaut designs to the Jason reactor, the first of which they built as a private venture at the Langley laboratories. This reactor first went critical on September 30, 1959 and was inaugurated by Sir John Cockcroft on November 24, 1959, who at the time expressed doubts about its commercial potentialities. Hawkers themselves believed that there would be a market of possibly two a year and in fact two, so far, have been installed, the LFR at Petten in Holland and Nestor at Winfrith.

Experiments were continuing on the system to increase its power and adapt it to different research requirements and runs had been made at 100 kW with a restricted coolant to demonstrate its safety at these higher ratings. Although another company may take over the key members of the design team and the existing design drawings there would still be a considerable backlog of know-how to assemble and the probability of this country now being able to offer an Argonaut type reactor for sale around the world seems small. A contributory cause of the shut down must be the havering of the various government departments on granting funds for university research reactors and a second cause must also be the expected decision of the Minister of Transport not to proceed, at least for the time being, with the construction of an organic moderated ship reactor, the design which Hawker Siddeley submitted to the Ministry as the result of the call for tenders last year.

Not all the company's activities were unprofitable; a considerable number of outside development contracts were in hand, the business of Nuclear Engineering, Ltd. (the manufacturer of shielding containers) had been placed on a solid footing and a significant expansion was forecast, and the company had also taken the lead in graphite impregnation which, if not a large income producer at the present, at least holds considerable promise for the future. One suspects that Group policy decisions outside the field of nuclear energy must also have had a bearing on the decision as there has been a considerable reorganization within the Hawker Group over the past months, and it would seem that no serious attempt was made to maintain the company as a research organization on the lines of the Parsons Nuclear Research Centre. The impressive success of the Parsons enterprise demonstrates that such an organization can be made to work in the United Kingdom but perhaps this is no proof that two such organizations could exist side by side.

The formation of Nuclear Developments as a joint holding company by ICI, Rolls-Royce and Rio Tinto to manufacture fuel elements for nuclear reactors can be interpreted either as a natural result of the recommendations of the Select Committee that the Authority should off-load to industry more of its routine operations, or as a beginning of a real break in the AEA's monopoly of uranium fabrication and processing. Probably the true interpretation lies somewhere in between. It should be made clear from the outset that the aim of the new company is to be in a position to supplement the Authority's existing fuel element fabrication facilities when these become saturated. The Authority is the only organization able to own the fuel at the present time in the United Kingdom and it is the sole owner of all British data relating to uranium treatment and fabrication. If competition were envisaged one would expect the Authority to remain in a commanding position for many years to come. It would require a large number of production short-cuts and a great deal of experience to offset the Authority's own considerable background in the handling of uranium or the fees they would charge for divulging the information that they had.

In the short term, the new company's operations will be confined to negotiating access agreements, establishing future terms of operations and preparing factories. It must be three or possibly four years before any fabrication work on a large scale can commence. In the mid term view it is anticipated that the company will act as a subcontractor to the Authority and that fuel will be supplied to a reactor via the Authority and will carry the Authority's guarantees with it. In the long term, however, one must anticipate that the accumulated experience of the company will begin to produce results and that it will take over from the Authority much of the responsibility for fabricating elements for production line reactors. At no time is it likely that there will be any real commercial competition and it would only be in the event of a second consortium arising that this could materialize.

Gloom has settled rather firmly over a number of companies in the United States with the cancellation of the American Nuclear Aircraft Project (although the companies have been told that the AEC will shortly be discussing new research programmes to the value of $25 million relating to the development of high temperature materials and involving somewhat similar backgrounds and possibly leading to the construction of a reactor). It has always been difficult to see the real objectives of the programme (except of course to get a nuclear plane flying) even as a military exercise. Whilst we do not feel really competent to comment on military strategy (particularly American), the marginal advantage that the nuclear powered aircraft would seem to have over conventionally fuelled aircraft always seemed to be of negligible significance compared with the difference between the striking potential of manned aircraft and a rocket force, especially one based upon a mobile target such as a submarine. The idea of a nuclear powered flying tug has always been intriguing but hardly worth the development cost at this point in time. What seems unfortunate is that in view of the progress that has been made on the development of aircraft-type engines the programme should be cancelled at this stage (see page 199 *et seq.*).

There is to be no cut, however, in the programme for developing nuclear powered space vehicles; rather the reverse. With Russia now having put a man into space the prestige battle to get to the Moon and beyond is on with a vengeance and no expense is going to be spared. We should not be surprised, nevertheless, if the reactor side of the space programme did not again come in for revision in the near future owing to the pressure of meeting more immediate space objectives.

View of the Trawsfynydd site from the Goliath crane.

World Digest

International

ENEA Ship Studies

Two technical working parties have been set up by the European Nuclear Energy Agency's study group on nuclear propulsion. The first of these will make a comparative survey of national economic studies of nuclear propulsion and will examine economic potentialities of reactor systems either under construction or envisaged. It is expected that this survey will cover those systems which are being developed with Euratom participation as well as those under consideration in the U.K. and Scandinavian and other countries. The conclusions of the first party will be taken into consideration by the second, which is charged with selecting a type of ship and reactor suitable for a joint European undertaking and with formulating proposals for the construction and operation of such a vessel on an international basis. Such a joint undertaking would, like the other European projects already established by ENEA (Eurochemic, Halden and Dragon) be open to participation by as many member countries as might be interested, or by Euratom itself representing the community countries. The two working parties are to report to the ENEA study group on September 15. The chairman of the study group is Dr. Sigvard Eklund, of Sweden, who last year headed an ENEA information mission on nuclear ship propulsion which visited a number of European countries to examine their national programmes.

A three-year research programme on fusion is to be undertaken by Euratom and the Max Planck Institute for Plasma Physics, Munich. Two-thirds of the cost, estimated at DM30 million, will be borne by the German Government and the rest by Euratom.

The American Government has requested that credits obtained from the Export-Import Bank for implementation of their collaboration agreement with Euratom should be used for dollar purchases only. The Euratom council reply is that while they will bear this request in mind they do not think it possible to insert a clause in the agreement which would exclude the possibility of buying nuclear materials from other sources.

Theme of the international congress to be held by Foratom in Paris, 1962, is " The creation and development of the European nuclear industry."

Two international seminars are to be held at Harwell and Saclay under the auspices of the European Nuclear Energy Agency. Designed for teaching staffs of universities and technical colleges, each seminar will have places for 50 participants. The Harwell one is being held July 10-21 and the Saclay one June 26-July 7. Further details can be obtained from the ENEA, 38 Boulevard Suchet, Paris 16e.

Euratom is seeking a collaborative agreement with the Argentine similar to the one under discussion with Brazil.

United Kingdom

Work on the 24-acre site for the 580 MW Sizewell nuclear station has started. Over 500 000 cu yd of soil is to be excavated before foundations can be laid. This is expected to take up to about July. During the same period access roads to the site and temporary buildings will be erected. Initial labour force is 300 men. This will rise to a peak of about 2 400 in 1962.

A successful Wigner energy release was recently carried out on Bepo at Harwell. This is the third release undertaken on Bepo, the previous ones being in 1954 and 1958.

Nuclear Developments is the name of a company formed by ICI Metals, Rolls-Royce and Rio Tinto for the fabrication of fuel elements for use in power stations. For comment see page 178.

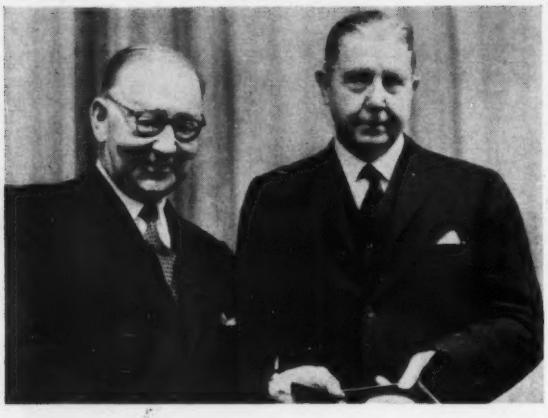
The Public Inquiry into the CEGB's proposal for a nuclear power station at Wylfa, Anglesey (*Nuclear Engineering*, January, 1961) will start on May 30. It will also deal with the Board's plans for a 400 000 volt double circuit overhead line from the station across Anglesey and the Menai Straits. Objections will be heard from local authorities and various national amenity organizations.

The preliminary draft of regulations under the Factories Acts, 1937-1959, for unsealed radioactive substances has been published (Stationery Office, price 1s. 3d.). Observations on the contents are invited to be sent in to the Ministry of Labour by July 31. In final form these regulations will be complementary to the Ionising Radiations (Sealed Sources) Regulations, 1961, a statutory draft of which has also recently been published (Stationery Office, price 9d.). Some comments on these two documents will be found on pages 184-186 of this issue.

Science teachers from schools in Southern England spent part of their Easter holidays on a five-day course at the Harwell Reactor School. It was arranged to provide them with an opportunity to extend their knowledge of nuclear physics and atomic energy, and to keep them informed of associated subjects. Attendance at the course was by invitation and the response was so favourable that it is likely to be repeated.

HS Nuclear Plant Shutdown

THE Hawker Siddeley Group has decided to close down its laboratories at Langley, Bucks, and to disband the Nuclear Power Company. The main activities of this company were development contracts, development and construction of Jason reactors, research on the Langley reactor, graphite impregnation and, as a result of its acquisition of Nuclear Engineering, Ltd., the production of shielded containers. The development contracts in hand will, where possible, be completed, but the future of the other four projects is not defined. If practicable, they will be placed within the Hawker Siddeley Group, but although there is some possibility that the graphite project would be taken over by another Hawker Siddeley company, it is unlikely that any of the other three would find an interested sponsor from within the organization. As a result, the construction of Jasons is unlikely to continue, but it is hoped that a customer will be found for the present reactor, including its research team, and for the shielded container business. When the decision was made, the company was employing 350 people and the majority of these will now be looking for alternative employment.



Sir John Cockcroft receiving the "Atoms for Peace" award from Dr. James R. Killian, Jr., chairman of the MIT Corporation. The event took place during the MIT centenary celebrations held early April. The award comprises a gold medal and an honorarium of $75,000.

Australia

The Government has decided to go ahead with the exploitation of the newly discovered uranium deposits at Rum Jungle (*Nuclear Engineering*, March, 1961). It has been established that the new deposits are larger than any other in the area and operations will be financed by reinvesting the profits earned on existing contracts.

A U.S. Naval radio station which might be powered and heated by a reactor is to be built in the northwest of the Western Territory, according to reports.

Moata, Australia's second reactor and one of the Argonaut family (*Nuclear Engineering*, March, 1960, p. 102; Oct., 1960, p. 428) has gone critical.

Brazil

A collaborative agreement for the exchange of information and personnel with Euratom is shortly to be signed. It will be similar to the pact concluded with Italy in 1958 (*Nuclear Engineering*, November, 1958).

Professor Marcelo Santos, of the Atomic Energy Institute, São Paulo University, has been appointed president of the AEC in succession to Admiral Octacilio da Cunha.

Canada

An order for Candu-type fuel assemblies to be tested in Zed-2 has just been completed. Each assembly consists of 19 Zircaloy cans of ceramic uranium oxide pellets.

France

An agreement with Euratom is being negotiated for the construction of a gas cooled enriched uranium reactor at Cadarache. It would be about 30 MW(th) in power level with gas temperatures of the order of 930–1 110°F.

West Germany

State support of up to DM3·2 million is to be provided for the MAN PWR design study —50% of the total cost. The projected reactor is of a two stage type and will have an output of 5 MW(e).

Government approval has been given to the expenditure of DM 170 388 200 on atomic energy during 1961. A supplementary budget of DM 21 150 000 to support the development and construction of prototype reactors has also been approved. Of the main appropriation DM 12·45 million will go towards the education of engineers and technical assistants, DM 55 million towards the completion of institutes, DM 16·27 million for the Desy project at Hamburg, DM 42·3 million towards Karlsruhe, DM 1·52 million for the GKSS project, DM 1 million towards documentation, DM 12·4 million for isotope techniques and nuclear chemistry, DM 1·8 million towards uranium surveys, DM 7·413 million towards radiation protection, DM 12·308 million for CERN, and DM 1·57 million towards the IAEA, leaving a balance of DM 6·3 million for other expenses.

Siemens-Schuckertwerke are showing a 0·1 W training reactor at this year's Hanover Fair. The core comprises plates of polyethylene, as moderator, with uranium oxide. The critical mass is about 700 g of U^{235}. Shielding is provided by lead and water.

Fuel for the 15 MW high-temperature AVR reactor at Julich is to be fabricated by Nukem from 147·7 kg of 20% enriched uranium supplied by Mallinkrodt Chemical Corporation, America. Criticality of the reactor is now expected to be postponed from late 1962 until early 1963.

India

A sum of £38·25 million has been earmarked for the Tarapur nuclear power project, it was recently disclosed in the Lower House, and £1·875 million is to be spent on expanding the Trombay fuel element processing plant in order to meet the requirements of the Tarapur station. Other appropriations under the third Five-Year Plan announced include £1·875 million for the irradiated fuel processing plant under construction at Trombay and £6·75 million on developing the Jaduganda uranium mines. A mill with an ultimate capacity of 1 000 ton/d is envisaged, costing £3 375 000 and taking 3 years to complete.

Italy

Information centres have been established by the National Committee for Nuclear Energy in Turin, Milan, Naples and Bologna. They are equipped with libraries, lecture and projection rooms and are intended for use by the local education authorities.

CNEN has signed a contract with Fiat and Ansaldo for the design study of a nuclear propelled tanker and it is now certain that Euratom will contribute towards the project. The contract is initially for two years and the cost of the project is estimated at about $3 million, of which it is hoped that 40% will be borne by Euratom. The projected vessel will be equipped with a water reactor of Italian design and have a power output of 23 100 s.h.p. Fiat are to be responsible for reactor studies and Ansaldo for ship design. CNEN will contribute technical facilities and staff.

Thirty-six scholarships are being offered by CNEN for the training of staff for the CNEN-Fiat-Ansaldo marine project. Twelve will be for naval and mechanical engineers to specialize in naval architecture, 12 for mechanical and electrical engineers to specialize in reactor problems, six for physicists, engineers and mathematicians to specialize in reactor physics, and six for engineers or physicists to specialize in safety and health physics. CNEN is to contribute 550 million lire (about £310 000) for the provision of equipment, including, probably, a reactor.

Hidden Contract for Uranium

BRITAIN faces the prospect of having to buy 12 000 ton of uranium oxide from Canada in addition to the 10 000 ton already being supplied under existing stretched out contracts. A letter of intent signed by the AEA in 1957 undertaking to purchase the oxide in 1963-66 has come to light and while the AEA might well argue that it is not a binding contract the Canadian official view is otherwise. It is likely that while insisting that Britain keeps to her promise the Canadians will probably be prepared to accept a lower price than that quoted in the letter (about £2 17s/lb or £70 million for the total amount) and also accept a stretched out delivery period. The AEA would naturally like to contract out of the deal, as to go through with it will probably cause some embarrassment in their dealings with other suppliers. On the other hand to engage on what would turn into a first class legal wrangle (the state of the uranium industry would not permit Canada to step down) would be imprudent and could also lead to an estrangement within the Commonwealth. Indicative of the importance of the issue is that negotiations based on the letter are to be carried out at ministerial level.

At a ceremony on March 23 the Ispra Research Centre was formally handed over to the Euratom Commission. More than $42 million are to be spent on the laboratories, which by 1962 will employ some 1 500 scientists and technicians. Before the ceremony the foundation stone of a European school similar to the establishments at Luxembourg and Brussels was laid at Varese, near Ispra.

Indonesia

President Sukarno on April 9 laid the cornerstone of the Institute for Atomic Energy's laboratory at Bandung, Java. Among its facilities when completed will be a General Dynamics Triga, to be financed by a $350 000 grant from the U.S.

Japan

Construction work has started on the 12.5 MW(e) BWR plant at Tokai Mura. It is being built by General Electric Japan, a wholly owned subsidiary of General Electric of America and is scheduled for completion early 1963. The 150 MW gas cooled station under construction at Tokai Mura by General Electric of England is due to be commissioned later that year.

Twenty-year programme recently announced by the Government allows for a nuclear power capacity of 1 000 MW by 1970, rising to between 7 000-9 500 MW in 1980. The first nuclear-propelled ship will probably be launched between 1968-70.

Uranium dioxide fuel fabricated by a swaging process developed by Mitsubishi Atomic Power Industries, Tokyo, is to be tested in the Westinghouse testing reactor, Waltz Mill, Pennsylvania.

Netherlands

An IAEA team have inspected the 20 MW(th) HFR nearing completion at Petten and found it satisfactory from the point of view of safety. They have also made recommendations as to operating procedures. A similar inspection was made by the IAEA in 1959 on the Diorit reactor at Würenlingen, Switzerland.

Peru

The German Government is to contribute DM 134 000 towards a uranium survey being carried out by five experts from the Instituut für Bodenforschung, Hanover. Work started in April and is expected to last four to five months.

Poland

A protocol for collaboration in nuclear energy for peaceful purposes has been signed with East Germany. It covers the period 1961-65.

South Africa

A uranium refining pilot plant has been put into commission at the Government Metallurgical Laboratories, Johannesburg. It has an annual capacity of 100 tons of uranium and will be used primarily as a research project for research and development into refining methods. Prototype fuel elements to be tested in the Pelindaba reactor, due to be commissioned in 1963, will be fabricated there.

Spain

Details of the 250 MW(e) station proposed to be built by CENUSA at Castrejón on the Tagus, near Madrid, have been submitted for official approval to the Ministry of Industry. This is the second proposed nuclear power station in the country for which government permission to build is sought.

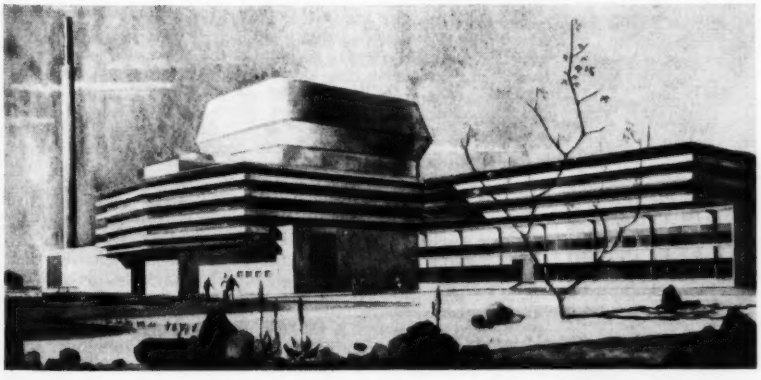
Subcritical and critical assemblies are to be built at the Junta Energia Nuclear laboratories to provide data for the proposed 30 MW organic moderated heavy water cooled reactor. These plans follow the completion of a cost study of the project carried out by the Bechtel Corporation, of America, in conjunction with JEN and Tecnatom.

Turkey

Natural fuel for a subcritical assembly at Ankara University has been sent from the U.S.A. It amounts to 5 500 lb and cost $100 000, which is to be paid out of U.S. Mutual Aid Funds. The sub-critical assembly is being equipped with instrumentation acquired in the U.S. through the IAEA.

Yugoslavia

The IAEA is to participate in the supply of a Triga reactor and fuel from the U.S.A. Funds have already been allotted by the U.S.AEC towards the reactor (*Nuclear Engineering*, November, 1960) and the Yugoslav Government is now able to place the project on the same footing as that afforded by the trilateral agreement for the supply of a Triga and fuel to Finland. The Yugoslav reactor will be sited at the Nuclear Institute, "Jozef Stefan," Ljubljana.



Work will shortly start on the construction at Pelindaba, near Pretoria, of the building that will house South Africa's first reactor. This will be based on the design of the tank type ORR, Oak Ridge, but will incorporate several important modifications to meet the requirements of the Atomic Energy Board's research programme. Construction of the reactor will start next year and criticality is expected to be achieved towards the end of 1963. Initial power output will be 6·6 MW which later will be increased to 20 MW. About 70% of the construction for the reactor and all of the building housing it will be undertaken by South African companies. Main contractors are The Robert Construction Co. Core components will be supplied by Allis-Chalmers.

U.S.A.

Recommended conditions under which state governments can assume responsibility for the legal control of certain radioactive materials have been approved by the AEC and circulated to the state governors. They implement the scheme promulgated by a 1959 amendment to the Atomic Energy Act which enables the AEC to surrender their legal control of radioisotopes and subcritical quantities of source and special nuclear materials. The recommendations emphasize the need for uniformity in radiation standards and state regulation programmes compatible with the AEC's own regulations. No recommendations are made as to whether the states should have regulations which cover all radiation sources, including those not covered by the AEC, such as X-rays, radium and accelerators.

The AEC has decided that the new plutonium production reactor under construction at Hanford will also be used for power production. Generating plant with 700 MW(e) capacity will be installed and the output distributed by Bonneville Power Administration. The reactor is due to be completed by 1962 and the generating plant about two years later.

Reactors and critical assemblies at the Brookhaven National Laboratory were closed down during March following criticism of the operating and maintenance procedures. In the nationwide survey carried out at the request of the AEC after the SL-1 incident it was found that the Brookhaven procedures were inadequate despite the fact that reactors have been safely operated there for 11 years. As a consequence the Medical Research Reactor and Neutron Source Reactor, together with two critical assemblies, were closed down pending a review of the operational and maintenance arrangements. Operation of the Graphite Reactor was allowed to continue until the date scheduled for routine shutdown was reached. A review of the procedures applicable to this reactor was then made; two days later, the reactor was put into operation again.

The AEC reactor safeguards advisory committee has questioned the advisability of operating the 225 MW Indian Point PWR at full power without in-pile monitors. Consolidated Edison, the designers, are confident that the removal and scanning of fuel elements at frequent intervals will provide a sufficient check on core behaviour. The committee feel, however, that the question will not be properly answered until relevant data is obtained from operating the reactor at levels less than full power. Criticality is expected to be achieved in November.

Criticality was achieved on April 3 in the Snap-2 development systems (S2DS) reactor at the Canoga Park laboratories of Atomics International. A 50 kW(th) unit measuring 13 in by 9 in and fuelled with a uranium-zirconium hydride alloy, it is the second reactor to be put into operation under the Snap-2 programme (*Nuclear Engineering*, October, 1960). The first was the Ser (Snap experimental reactor) which during a year's run generated 225 000 kWh of heat and on one occasion ran continuously for 1 000 hours at design conditions of 1 200°F.

Criticality was achieved on March 30 in the Ml-1 at Idaho Falls. It is a 300 kW(e) gas cooled reactor (*Nuclear Engineering*, January and April, 1961) developed by Aero-Jet.

Fuel elements for the EGCR at Oak Ridge are to be fabricated by Westinghouse. They will consist of ceramic uranium oxide pellets clad in stainless steel and will be arranged in clusters of seven within a graphite assembly (*Nuclear Engineering*, January, 1961, and page 183 of this issue). Fuel elements to be supplied will number 1 739, which will be sufficient for the initial loading with 300 to spare. Delivery is expected to start next March.

President Kennedy's proposals for the 1962 atomic energy budget at $2 628 million are up by $30 million over the Eisenhower proposals submitted in January. The chief features of the proposals are $60 million for making the NPR at Hanford into a power reactor (see separate item), cancellation of the aircraft nuclear propulsion programme (see box); $26 million appropriated for start on the construction of the Stanford University $114 million linear accelerator, an extra $5 million for project Rover, $8 million extra for Bore, and $7 million for a reactor in the Antarctic. Uranium procurement costs are down by $16 million and expenditure on fissionable materials reduced by $32 million. The proposals also account for 10 new Polaris submarines. He had already increased the number of these submarines in 1961 from five to 10 and from 1963 is to order 12 a year.

Work is progressing on the construction of the fusion experimental assembly DCX-2 at Oak Ridge. This is an improved version of the DCX-1, which has been in operation for three years. The principle of this type of machine is to build up a low density plasma by injecting a beam of hydrogen molecular ions across a magnetic field along which there is a carbon arc. The DCX-2 is designed to eliminate some of the deleterious effects of the arc by allowing the plasma to build up through collisions of beam molecules with the arc, which is then turned off (*Nuclear Engineering*, October, 1960). The machine is expected to be ready for operation by the autumn.

The Los Alamos Molten Plutonium Reactor Experiment No. 1 (Lampre-1) achieved criticality on April 3. The reactor, which uses a molten plutonium-iron alloy fuel and operates at about 950°F, is designed to produce 1 MW(th).

The National Aeronautics and Space Administration laboratories at Plum Brook, near Sandusky, Ohio. The AEC have issued a licence for the light water reactor there to be operated at no more than 100 kW. Although designed for operation at 60 MW(th) fabrication and staff problems (*Nuclear Engineering*, February, 1961) have led to a delay in its completion.

An operating licence is to be issued by the AEC for the 100 MW reactor at the Texas Agricultural and Mechanical College. It is later planned to modify the reactor to operate at 5 MW.

Microscopic cracks found in welds in the reinforcement grid beneath the core support plate of the Dresden reactor have led to further delay in startup of the reactor. Although the cracks have been described as being common in welds of this type the AEC has asked for time to examine their significance.

The third annual meeting of the Inter-American Nuclear Energy Commission (IANEC) is scheduled to take place between May 9 and 13 in Washington D.C.

Aircraft Propulsion Projects Cancelled

UNDER President Kennedy's atomic energy budget for 1962 the 14-year-old aircraft nuclear programme has been cancelled in its entirety, resulting in a reduction for the year of $35 million for operating expenses and $18.2 million on capital expenditure. Since 1948 the AEC has spent about $450 million on the programme, the Air Force $520 million and the Navy $15 million. The companies affected by the cancellation are General Electric who have been working on the direct cycle approach and Pratt & Whitney who have been tackling the indirect cycle system. These companies will probably be asked to participate in a $25 million research programme on high temperature materials directed to non-aircraft nuclear technology. It might well include the construction of a high temperature reactor. Commenting on the cancellation of the aircraft programme Mr. David Shaw, of General Electric, said they had told the Government that an experimental flight could have been achieved by 1963 for less than $200 million.

Reactor building on the University of Washington campus, Seattle. It houses an AMF "Educator" which was recently put into operation and will be used for training physicists, engineers, chemists and other technicians in allied fields.

A second set of 17–4 PH stainless steel control rod drives heat treated at 1 100°F instead of at 900°F, as specified for the first set, has been ordered for the Indian Point PWR plant. The order was placed as a consequence of the failure of the Dresden control rod drives of the same steel. In the Dresden reactor, control rod drives material which has aged at temperatures below 1 000°F has been removed and replaced with steel treated similarly to that for Indian Point.

A $500 000 study into the mixing, diffusion and circulation rates of ocean waters is to be made for the AEC for the purpose of predicting the movement of radioactive isotopes. The study will be carried out by the Lamont Geological Observatory, Pelisades, New York, and Pneumo Dynamics, of Washington, will design and build the necessary equipment for work to start next summer near Bermuda.

Correspondence

EGCR Fuel Element Design

Sir,—I wish to offer my compliments on the contents of your January issue describing the design of the Trawsfynydd Plant. The information presented brings out many of the more recent technical developments of the Magnox reactors and the engineering approaches currently in vogue in the United Kingdom. The description of the Tokai-Maru approach to earthquake resistance by Bailey and Head also adds considerable insight to the treatment of large seismic forces in gas-cooled reactors.

The article by W. F. Banks entitled "EGCR-Descendant of Calder Hall" presents much of the EGCR design correctly, but it may have caused some confusion in your readers' minds. The plant described is, in fact, being designed jointly by Allis-Chalmers, Kaiser Engineers, and Oak Ridge National Laboratory for the AEC at Oak Ridge, Tennessee. The fuel element design described is one which Allis-Chalmers proposed for the EGCR and is very much like the fuel element to be used in the actual installation. The EGCR fuel element is being designed by the Oak Ridge National Laboratory, but in order to minimize any changes required in the plant arrangement it is similar to the geometry selected by Allis-Chalmers. The design of a fuel element involves many subtle details which influence the performance and cost of the assembly. I believe that the following comments will bring the design into better perspective:

1. Dimensional tolerance on the fuel pellet and the stainless steel cladding have a considerable influence on costs, and the optimum selection of these to assure satisfactory structural integrity and performance is a major problem. In particular, clearance between the pellet and the cladding determines the mode of collapse of the tube against the pellet under external pressure and greatly affects the central oxide temperature.

2. The oxide temperature is extremely important in establishing fission gas release rates, and assurance that it will be held below a given value is a key consideration in the EGCR fuel element design.

3. Positioning of the fuel elements in the sleeve is important to the hot spot analysis, and both ORNL and Allis-Chalmers addressed a great deal of attention to this matter.

4. Space allowance for axial expansion and strength of the unsupported cladding around the expansion void during low power operation are important considerations in the fuel assembly geometry.

5. The chemical composition of the oxide has great importance in the fission gas retention properties of the fuel element.

6. The end closures for the cladding are important because they represent a major fabrication cost, and the selection of an inexpensive, reliable, and inspectable closure method is a determining factor in the fuel element adequacy.

7. The graphite sleeve is a necessary evil in the EGCR, and its elimination would reduce the EGCR fuel cycle costs.

8. Fuel element length will ultimately be important in future reactor optimization. The EGCR shuffles fuel in groups of three assemblies so that two assemblies per channel instead of six would be ideal from a handling standpoint and would greatly reduce the number of end closures. This must be counterbalanced against axial expansion effects and problems resulting from an element failure. The AGR stringer design has many handling advantages in this regard.

9. The spacers between the end spiders must be designed for minimum pressure losses and must be attached in a way which will not damage the fuel cladding. Development of a brazing technique which does not harm the metallurgical properties of the cladding is fundamental to the design.

In the plant design Allis-Chalmers is responsible for the graphite structure including the top grid, the bottom plate and the peripheral restraints, the BSD system layout, the control rod drives, the reactor service machine, and the reactor control instrumentation. A meticulous job was done by Allis-Chalmers in determining the dimensional position of the graphite blocks in the reactor based on the neutron flux distribution pattern computed by ORNL. The EGCR neutron flux is greatly distorted by the effect of the experimental loops, and graphite shrinkage is probably more severe than might be encountered in a simple power reactor of equivalent power density. The sealing of the fuel channels has been greatly simplified by the successful manufacture of the long core blocks, and a great deal of credit is due the National Carbon Company for meeting this challenge under firm price and schedule commitments.

Kaiser Engineers is responsible for the design of the reactor vessel and coolant system, the steam system, and the charge machine as well as the plant layout. The very close nozzle spacing in the EGCR necessitates taking full advantage of the structural reinforcement provided by the nozzles themselves. The evaluation of such structures has very little design precedent, and the verification of the design adequacy has proved to be a major engineering undertaking. The designs of the coolant system and the steam system have similarly been major engineering accomplishments which will contribute to the success or failure of the installation.

I feel that the complex mechanisms designed by Allis-Chalmers for the service machine and the control rod drives and by Kaiser Engineers for the charge machine deserve special comment. In each case an effort has been made to evolve a design which considers very pessimistic contingencies and if proved out successfully will give the plant operator a true on-load fuelling and maintenance capability. Such mechanisms do contribute significantly to the capital cost of the reactor plant not only in the cost of the machinery itself but in the tight tolerances which are imposed on the core and vessel structure. Thus the ability to accomplish this purpose at reasonable cost is fundamental to the justification of these features. The need for them becomes less important as fuel lifetime is extended and reactor components become more reliable, but an economic incentive in this direction will always exist.

Speaking as one who has had both to criticize and to defend the work of the EGCR designers, in the capacity of responsible design reviewer for the AEC, it has given me some pleasure to see that few of the original design objectives have been surrendered in the EGCR. Still it would be unfair to say that economics could not justify a different course of design in some areas. The use of CO_2 in enriched gas-cooled reactors is very much a live issue in the United States and may be justifiable even if some sacrifice in coolant temperature must be accepted, and therefore the AGR continues to be of great interest in the United States. The use of stainless steel for fuel element cladding does not penalize the design as much as one might think, although the EGCR's 20 mil cladding introduces more poison than would the 10 mil cladding of the AGR. The seven-rod fuel cluster of the EGCR was selected on the basis of optimum heat transfer surface per dollar of fuel fabrication cost. Larger clusters of smaller diameter fuel elements as considered in the AGR are not ruled out, however, but hinge on our ability to reduce fuel fabrication costs. In view of these many variants possible in power plants of the EGCR/AGR class I feel that there is still much room for advancement and alteration in the design of this type of power plant.

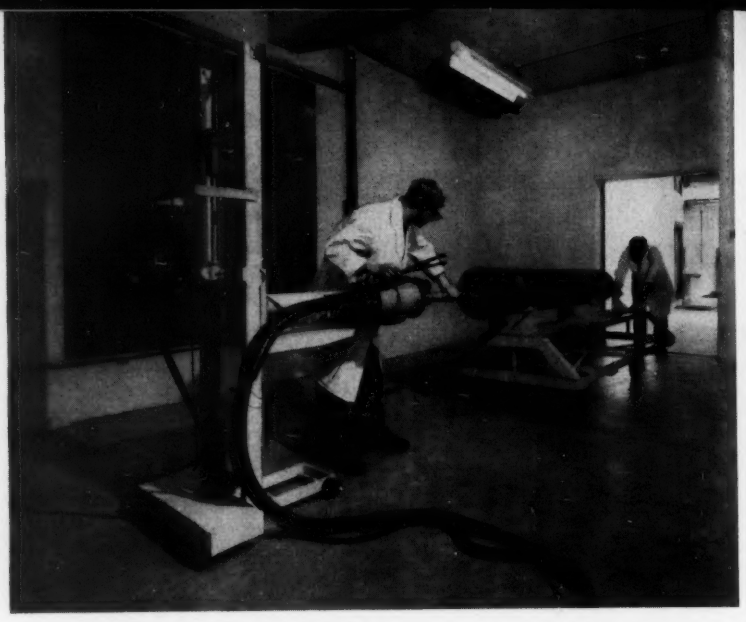
M. BENDER,
Head Reactor Division Design Dept.,
Oak Ridge National Laboratory.

Beryllium v. Stainless Steel

Sir,—In the brief summary of AGR fuel costs outlined in your last issue (page 132) and in which you compare beryllium and stainless steel cladding, an important omission has been made. This is the rent or interest that must be paid on the fuel charge within the reactor and the fuel held up in the manufacturing and post irradiation cooling stages. Accepting the figures you give for the additional cost of uranium in stainless steel clad elements (£60/kg) the additional capital charge that must then be included will amount to an annual charge of £4.5/kg of fuel in the reactor. This is based on an interest rate of 5% and a hold-up outside the reactor of 50% of one charge. At the 75% load factor you cite, this will imply an additional unit cost of nearly 0·03d/kWh. It would seem then that even if one is faced with the very high cost beryllium fabrications you indicate, beryllium canning in the AGR would still show an advantage over stainless steel sufficiently large for a programme of beryllium AGR central stations to be initiated, and of a magnitude which would see the cost of beryllium ultimately much reduced.

A. T. Philipps.
Reading.

Sealed Sources Regulations



AGR component being X-rayed at the Derby works of International Combustion Ltd.

AFTER a remarkably long period of gestation the statutory draft of the Ionising Radiations (Sealed Sources) Regulations 1961, Draft, under the Factories Acts has been published (by H.M.S.O. at the price of 9d.). It incorporates many changes from the preliminary drafts—even of title—and is not just another cock-shy for interested parties. This new draft is a formal one published in accordance with the special procedure set out in the Second Schedule of the Factories Act, 1937. Assuming that no major objections are raised which require a formal inquiry, with its attendant delay, the Regulations are in a form ready to come into force quite soon.

The Regulations, when in force, will apply to premises to which the Factories Acts are applicable and in which:

(1) Any sealed source, as defined, is or is proposed to be stored, manipulated, maintained, operated, used or installed,

(2) Any machine or apparatus intended to produce ionizing radiations is or is proposed to be operated or used (but excluding certain medical X-ray machines),

(3) Any machine or apparatus in which charged particles are accelerated by a voltage of not less than 5 kV, is or is proposed to be operated or used.

The definition of "sealed source" is "any radioacfive substance bonded wholly within material or sealed in a container together with its bonding or immediate container, not being a substance sealed in a container solely for the purpose of storage, transport or disposal."

Much has been learned since the palmy days of 1948 when the Radioactive Substances Act of that year defined radioactive substance in such a way as to include the walls of a room—and the people in it. The new draft Regulations specifically exempt certain sealed sources with a surface dose rate of 10 mr/h or less and apparatus used only for receiving visual images sent by television and operated at a voltage of not more than 20 kV. Also exempt from this Code are nuclear fuel elements and such plant or installations as are specified in Section 1 of the Nuclear Installations (Licensing and Insurance) Act, 1959, e.g., nuclear reactors.

Under the powers given to the Minister of Labour by the Factories Acts, the Regulations pertaining to both sealed and unsealed sources (q.v.), when in force will be potentially applicable to any place which is subject to those Acts. One or the other, or both, as appropriate, may be applicable for instance to a building operation, wherever it is carried out; in this way the Regulations—and specified parts of the parent Acts—may apply during the construction, structural alteration, repair or maintenance of a building of any kind In this way, incidentally, the statutory requirements may be introduced into premises not otherwise under the Factories Acts.

The general rule under British factory legislation is that the occupier is *prima facie* liable for infringements of the legal requirements although in practice there are a number of exceptions to this rule; by treating the owner or hirer of the sealed source (a term which we shall take to include machines and apparatus as defined) as the occupier, a similar picture of responsibility is presented here. On the face of it, if a contractor takes a sealed source into the premises of another in order to carry out some work, the contractor will in general be responsible for complying with the terms of the Regulations. But, in some cases—as instances under the Factory Building Regulations have demonstrated—there may be a dual responsibility on the grounds that a liability placed by the Acts on a contractor does not relieve the factory occupier of a liability already placed on him.

Although the wording of the draft Regulations indicates that the contractor in such a case would be regarded as the occupier with reference to the use of sealed sources, complications are possible in practice. For example, a contractor may take sources into a factory which already has sealed sources in use under the Regulations; or a sealed source taken into a factory by a contractor might create a hazard at a workplace which the occupier is already under a statutory duty to maintain as safe. In such cases a dual responsibility may arise rather than a liability on the one party or the other.

The safe and sensible course to take in such cases is for all parties to take a real interest, so as to ensure that adequate precautions are taken whenever sealed sources are on any premises.

A brief paragraph in the draft makes it clear that the requirements are in addition to those imposed by the Factories Acts. This is not true of all Regulations made under the Factories Acts, some of which are in substitution of the relevant parts of the Acts. But the clear statement in the draft Sealed Sources Code means that factory occupiers and others who have duties placed upon them by the Acts, have to comply with the requirements of the Acts as well as with those of the Regulations; for example, a Factory Inspector can apply to a Court of Summary Jurisdiction for an order requiring certain precautions to be taken if work is carried on in such a manner as to cause risk of bodily injury to persons employed.

Standards of safety proposed take into account the latest recommendations of the International Commission of Radiological Protection and of the Medical Research Council, also of good safety practice. The schedule deals in a simpler way than the original preliminary draft with the maximum permissible radiation doses—the earlier attempt having been severely criticized. Safety should be "built-in" as far as possible and reliance placed on safe procedures (the lowest form of safety) only when better means are not practicable.

The principle of minimum exposure of personnel to radiation is written into the Code. Too easily one can come to regard the maximum permissible radiation doses as "tolerance levels" but the draft Regulations make it clear that this is not good enough. The word "practicable," incidentally, with which factory legislation is liberally sprinkled, is not the same as "conveniently." In short, minimum exposure means neither "maximum permissible" nor "minimum convenient" levels.

A feature of the proposed Regulations is the central position of H.M. Inspector of Factories. He has to be notified of the intention to start or discontinue using, storing, etc., sealed sources, also of the loss of sources. Records including the health register kept in accordance with the Regulations have to be available for inspection by him, as have all documents kept under the Acts; when a classified worker leaves a particular employment the employer has to send a copy of the man's radiation dose record to the Inspector. It is interesting to note that the draft Regulations have come into line with other nuclear safety legislation by requiring the health register to be preserved for 30 years.

Management decisions are called for at an early stage. Persons who are to be designated as classified workers have to be identified, for only they will be subjected to the full protective requirements and be permitted to undertake work with radioactive sources; competent persons will have to be appointed to supervise the observance of the Regulations; the person allowed access to the store must be nominated; also the important medical and monitoring arrangements will have to be made, as well as plans for training and instructing personnel in hazards and precautions, a matter which was omitted in the earlier drafts. In planning the use of sealed sources, management will need to give careful thought to safe procedures, for not only must work be effective but it must be safe.

Persons employed have themselves certain duties under the proposed Regulations as indeed they have under the parent Act which, as already indicated, continues in force unabated. In this way the employee has, according to the draft Regulations, to wear a photographic film or radiation dosemeter, to submit to medical examination and to notify the occupier if he has reasonable grounds for believing that any sealed source has been lost or mislaid. Under the main Act he must not " wilfully and without reasonable cause " do anything likely to endanger himself or others.

Those who manufacture plant incorporating sealed sources will be concerned with the Regulations under at least three headings; as occupiers of factories they will have to comply with relevant parts of the Code; as designers of plant they will have to make it easy for users of their products to obey the statutory requirements; they will have an interest and responsibility in the extra-mural activities of their employees who may be employed on the premises of other employers in installing, testing, maintaining and repairing the plant. Also, like users, they may be involved in the safety requirements for the transport of sealed sources, for which the Minister of Transport has promised statutory Regulations.

Listed baldly, the proposed statutory requirements appear to be onerous yet in practice many, if not most, of them are already familiar to well-run factories and other premises. On examination, the draft is seen to contain precautions which for other reasons are common practice in industries not handling radioactive material, e.g., shielding against danger, designating of process or classified workers, checking for defects in plant, medical supervision, the keeping of records, the appointment of a competent person—and much else. On analysis, the Regulations should not prove a deterrent to the growing use of sealed sources in industry but rather the reverse, as manufacturer and user will be provided with a firm set of ground rules upon which the design and operation of equipment can be based.

Unsealed Sources

HOT on the heels of the statutory draft of the Sealed Sources Factory Regulations has come the preliminary draft of the Unsealed Radioactive Substances Regulations (H.M.S.O. price 1s. 3d.) also made under the Factories Acts and bearing obvious signs of kinship. The essential difference in status of the two Codes is that the former is a statutory draft ready for transmuting into a binding Code of Regulations—unless critics press objections so as to produce more delay—whereas the latter is the first publication of legislative intentions, the precursor of the statutory draft.

The fact that the two drafts follow a similar pattern in their earlier portions throws into clear relief the differences between them. The reasons for the differences are usually apparent but there is one exception; it is not obvious why the one draft Code (Unsealed Substances) applies where radioactive substances are stored, etc., whereas the Sealed Sources draft applies where sources are, *or are proposed to be* stored, etc.

Where the two codes are dealing with the same subject matter, in general they use identical terms, except that the Unsealed Substances draft still speaks in terms of " persons employed in the processes " as did the earlier edition of the Sealed Sources Regulations, to be later replaced by the term " classified workers " for persons employed on work in connection with sources.

The term " classified worker " in the Sealed Sources Code also has reference to the place where the person works vis-à-vis a source. It is one of the criticisms of the Unsealed Radioactive Substances Regulations draft that the standard of precautions to be provided for an individual relates primarily to the work he does rather than to the place where he does it. Admittedly, there is an important connection between the two but anomalies seem more likely to arise where direct account is not taken of a person's location with reference to a potential hazard of the kind under consideration.

At the end of the Regulations are three schedules and in the first of these is a classified list of radionuclides. This is used for exemptions, among other matters. Thus, nothing in the proposed Regulations shall apply to any workplace or store in which the amount of radionuclides in the unsealed substance does not exceed:

(a) 1 μc in the case of class I radionuclides such as polonium–210 or uranium–233.

(b) 10 μc in the case of radionuclides in the other classes II, III and IV.

As there is a marked dichotomy in the draft which seeks to impose more precautions for the process worker than for his non-process colleagues, it is important to ensure that the basis of division is the soundest possible. This division has long been typical of factory legislation but in new circumstances such as these fresh thinking may be needed.

It is surprising for example that under the " Permit to Work " conditions laid down in Regulation 52, there is no reference to a person who has to examine plant in that place—this last Regulation covers persons who have to alter, repair or clean, but not examine, the inside or contents of an enclosure.

Further thought needs to be given to the proposals for dividing personnel in this way for the purpose of providing the different levels of protection. It may be found to be satisfactory when it is related to the control of persons entering an area where there is radiation or contamination, but the point merits more attention.

No young person under 18 years of age is permitted to be employed in the processes as defined. This does not appear to prevent such a person being employed in the vicinity of the processes or even being employed, with the authority of a permit to work, in a class A workplace or store, on work other than process work, where, in theory, comparable risks may arise.

Key definitions could usefully be examined for particular applications. This Code is remarkable for its attempt to be comprehensive—which on the whole is successful—but any set of rules made to apply to a wide range of premises from power stations to the smallest luminizing shop may reasonably be expected to be less than appropriate in some of its applications. If serious criticisms arise on this or other matters, they should be sent to the Ministry of Labour, who invite observations, by July 31, 1961.

" Sealed source " and " radioactive substance " have the same meaning as under

the Sealed Sources statutory draft. Radioactive substance is defined as "any substance which consists of or contains any radioactive chemical element whether natural or artificial and whose specific activity exceeds 0·002 μc of parent radioactive chemical element per gram of substance."

"Unsealed radioactive substance"—perhaps the most important definition in the whole Code—means "any radioactive substance that is not a sealed source" and includes a nuclear fuel element and any radioactive substance contained in any plant or installation of the kind specified in a particular subsection of the Nuclear Installations (Licensing and Insurance) Act, 1959. The latter lists plant designed or adapted for the "production of atomic energy by a fission process in which a controlled chain reaction can be maintained without an additional source of neutrons"—and other plant and installations prescribed by the Minister of Power (in England and Wales) or the Secretary of State for Scotland, and specifically including an installation designed or adapted for the manufacture or storage of fuel elements containing enriched uranium.

It is the function of yet other Ministers to be primarily concerned with radioactive waste discharge and disposal and the draft under review concentrates, as all Factory Regulations must, on the protection of the persons in their working environment from the hazards arising there. Nevertheless a clause might well have been added to the draft requiring that any gaseous effluent discharged from a workplace should be so disposed of that it does not enter the air of any occupied room.

A drafting point arises in connection with Regulation 16. From the definition of radioactive waste it seems that radioactive gaseous effluent is a kind of radioactive substance; yet that Regulation both requires every unsealed radioactive substance when not in use to be securely stored—and requires the ventilation to open air of stores where there is liable to be a radioactive gas.

Incidentally those who seek reference to a recommended number of air changes as a means of protection will search in vain. The parent Acts, which will apply concurrently with the Regulations have something to say about ventilation but there is no appropriate statutory guide as to linear air speed at fume cupboards and glove boxes for instance. Conditions will vary so much in the different kinds of factory and plant covered in this comprehensive Code that this omission seems reasonable—and it is in line with the usual tradition of Factory Regulations.

The system of relating precautions to the degree of hazard in a particular area has been developed and three classes of workplace and two of stores are proposed as shown in Table 1. To simplify calculations, the concept of a "unit" has been introduced and this is associated with the degree of hazard and the amount

Table 1. Grading of areas according to number of units

	Workplace	Store
Class A ..	> 1 unit	> 1 unit
Class B ..	>0·001 ≤ 1 unit	≤ 1 unit
Class C ..	≤ 0·001 unit	—

of the individual radionuclide; a brief selection of examples is given in Table 2.

This idea of using a unit in the way proposed is easy once the notion has been grasped and neatly gets over the difficulties otherwise encountered. If, for example, a spill is imagined and it is necessary to find out whether the special precautions of Regulation 45(4) are needed, reference to the unit table on which Table 2 is based provides the answer assuming that the amount and the particular nuclide are known. Nothing is said, however, about a mixture of nuclides, but some elementary adding should provide the answer.

The principle of minimum exposure to radiation, subject to overall maxima, the use of built-in safety, e.g., by shielding wherever possible and practicable, and the provision of safe layout, plant, equipment, systems and procedures, are emphasized.

Maximum levels are laid down for contamination and radiation. They embody key figures from the ones recommended by the International Commission for Radiological Protection and the Medical Research Council. The cumulative dose in rad should not exceed five times the number of years of age above 18, for instance; and the maximum permissible dose for process workers from X-rays, gamma rays, beta rays, electrons and positrons is 20 rad in air to the non-critical parts of the body—recorded over a calendar quarter. For those who are not process workers, the maximum in any calendar year is 3 rad, of which not more than 1½ rad shall arise from specified kinds of radiation, e.g., gamma radiation. For juveniles under 16 years of age, for the last figure the maximum is 0·5 rad.

The draft seeks to legislate very generally in parts and rather precisely in others. Thus it calls for "effective precautions" (unspecified) to prevent unwanted criticality in one Regulation but shortly afterwards is calling for a workbench of minimum dimensions of 4 ft by 1 ft 6 in. Now that criticality hazards have at last been recognized in the sphere of legislation, it is time to consider whether all that needs to be said has in fact been stated in this draft, or whether the Nuclear Installation (Licensing and Insurance) Act, 1959, should be used to cover all eventualities.

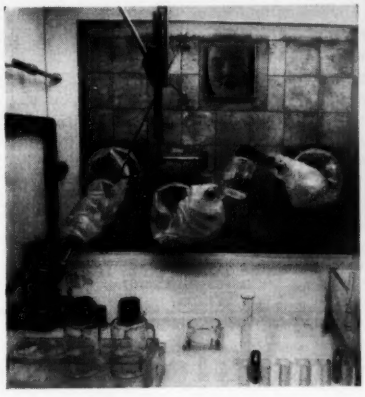
Inevitably safety has to an important extent to be attained by safe procedures and practice; the appointment of a

Table 2. Unit equivalents of selected radionuclides

Class	I	II	III	IV
1 Unit =	1 mc	100 mc	10 c	1 000 c
Radionuclides	Po^{210} Ra^{226} U^{233} Pu^{239}	Co^{60} Sr^{90} I^{131} U^{238}	Na^{24} P^{32} Sr^{89} Cs^{137}	Be^{7} C^{14} Kr^{85} Xe^{135}

competent person to supervise the compliance with the legal requirements has become almost commonplace in factory law. The qualifications of this "competent" person have not been closely defined for they will not necessarily be the same in different premises. It is tempting to ask for more definitions but they are often difficult to draw up and unsatisfactory and even inflexible when they do exist. (Factory law has flourished since the 19th century without a definition in the Acts of the word "accident".)

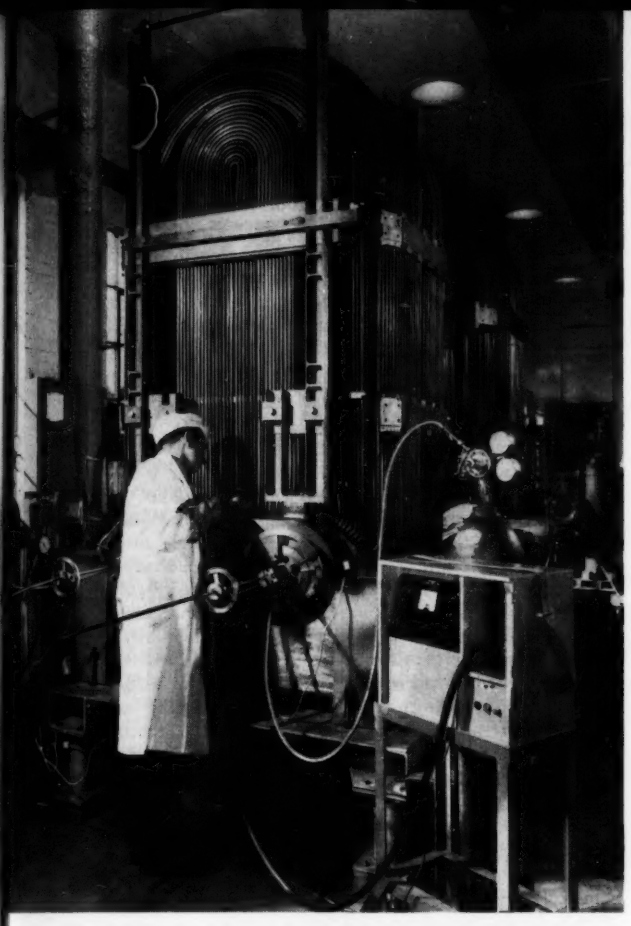
If there is real doubt or ambiguity, definitions help, for the law should be clear. The loss of a sealed source for



A process worker at the Radiochemical Centre, Amersham, handling a gamma emitting isotope.

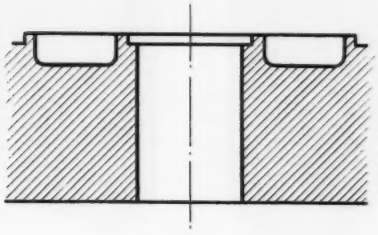
instance is a meaningful phrase but the loss of an unsealed radioactive substance is (at least in relation to some kinds) far less clear. That which goes down a drain or up a stack is waste as defined but when small amounts are mislaid or unaccounted for or possibly gone to waste, perhaps in a luminising shop or routine laboratory subject to the Factories Act, does this mean that a loss has occurred?

Finally, it is suggested that although these are draft requirements for application to factories, building operations and other work subject to the Factories Acts, they are also of some importance to those concerned with non-factory premises, such as research laboratories. As major codes, the two draft factory Regulations just published represent the work of a great number of persons highly qualified in this field. The codes are in fact setting a pattern of safety which many will observe voluntarily and which in due course will no doubt be taken into consideration by the advisory panel already set up under the aegis of the Radioactive Substances Advisory Committee with the following terms of reference: "To consider, in relation to persons working in research establishments (other than hospital research establishments), the safety and health questions arising from the use of ionizing radiations, and to report."



(Left) Leak testing tube plate connectors produced by internal welding.

(Below) Cross-section through tube plate to show machining preparation prior to welding tube.



Tube-to-Tube Plate Connections

By S. E. Gallant, A.M.I.W.

(*Welding Engineer, Foster Wheeler, Ltd.*)

ALTHOUGH the orthodox method of tubing a heat exchanger—boring the tube plate, inserting the tube ends and expanding them—is satisfactory for most applications a 100% pressure tight seal cannot be guaranteed. When one side of the circuit is subject to radioactive contamination as in a nuclear heat exchanger, a prime requirement is absolute integrity and each connection must therefore be made in such a way that there is no possibility of leakage. A second important factor is the avoidance of internal crevices and projections which might allow the accumulation of crud causing corrosion and base metal decay which would, in turn, result in leakage to the secondary circuit.

Faced with these problems recently, Foster Wheeler resorted to some novel welding techniques for the construction of heat exchangers for a small power reactor. It was agreed that the most suitable base material for the project was 1% chrome-½% molybdenum steel which is readily weldable. After several different designs had been proposed and considerable thought expended it was decided to find a way to weld the small bore, close pitch tubes to the 3 in thick, 12 in i.d. tubular header.

To weld the element tubes in this fashion appeared at first to be a formidable task because no commercial welding equipment or torch was available with which to reach around and between these closely pitched tubes.

It was soon realized that the weld would have to be made from inside to outside. This presented the problem of how to make a weld located in a position that could only be viewed with the aid of an introscope. As some sort of welding gear had to be passed through the bore of the tube it was impossible to have both the introscope and welding gear in the weld position at the same time so thoughts were focused on a way to make a sound weld without the operator being able to see the operation.

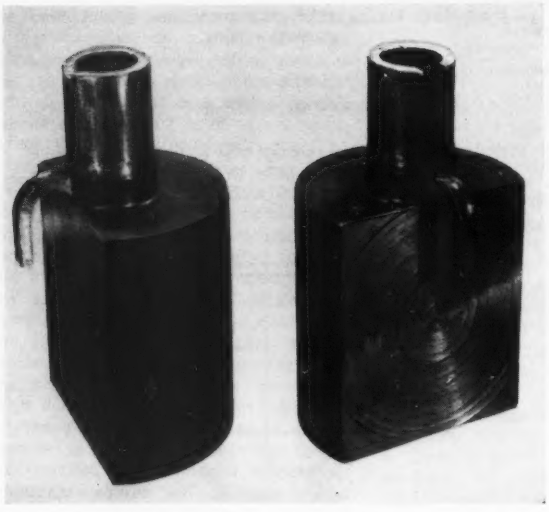
The solution was a fully mechanized automatic inert-gas tungsten-arc weld that could be reproduced for as many times as required after correct welding conditions and procedures had been established.

After the inception of the idea hundreds of test welds were made to various conditions and designs before what was considered to be a sound method was produced. Since the establishment of a finalized method, approximately 8,000 welds have been completed.

In order to achieve a weld of acceptable quality between a thin-walled tube and the heavy tube plate it was necessary to machine away the surface of the tube plate to make it of a comparable thickness to the tube wall. When this has been done a spigot type stub remains on the tube-plate surface which is of a size suitable to take the outside diameter of the element tube. The design that was decided upon enabled a weld to be made that was positioned ⅛ in from the header tube-plate surface. By using this joint geometry the weld is made away from the mass of base metal and in consequence it does not suffer from rapid quenching which maintains the weld and heat-affected zone at an acceptable hardness value.

As the first approach to the weld has to be made through a 5-in diameter access hole in the centre of the header end cap and then through the header bore for a distance of up to 48 in, a remote handling gear was designed. This consists of a movable boom with an inert-gas welding torch at the extreme front end. To avoid possible damage to the welding torch while being positioned, a dummy torch is used to establish correctly the position of the boom. After fixing the boom position, the dummy is withdrawn, and the torch is substituted. All this manipulation is achieved through remote mechanical controls situated on the rear end of the boom which is external to the header.

When the position of the torch has been correctly established and welding is ready to start, an automatic control incorporated in the boom and regulated from outside the



Typical specimen welds of tube-to-tube plate produced by internal welding.

header takes over and completes the joint. The control panel is equipped with electronic valves and interlocks which function in their required sequence to ensure that all the services such as torch cooling water, inert-gas coverage, high frequency arc initiation purge, welding current, torch rotation at the pre-set speed and time period, and crater filling current run off, function correctly. The whole welding cycle takes place automatically after a switch is engaged. A recording instrument is also incorporated in the circuit which gives a permanent graph record of the welding current and cycle period and, as each weld is made, the relative tube number is marked on the graph. This graph incidentally, gives a very good indication as to the quality of the weld but cannot be accepted as the final answer and in consequence a rigid system of inspection exists by which each row of tubes must be approved before commencing to weld the following row.

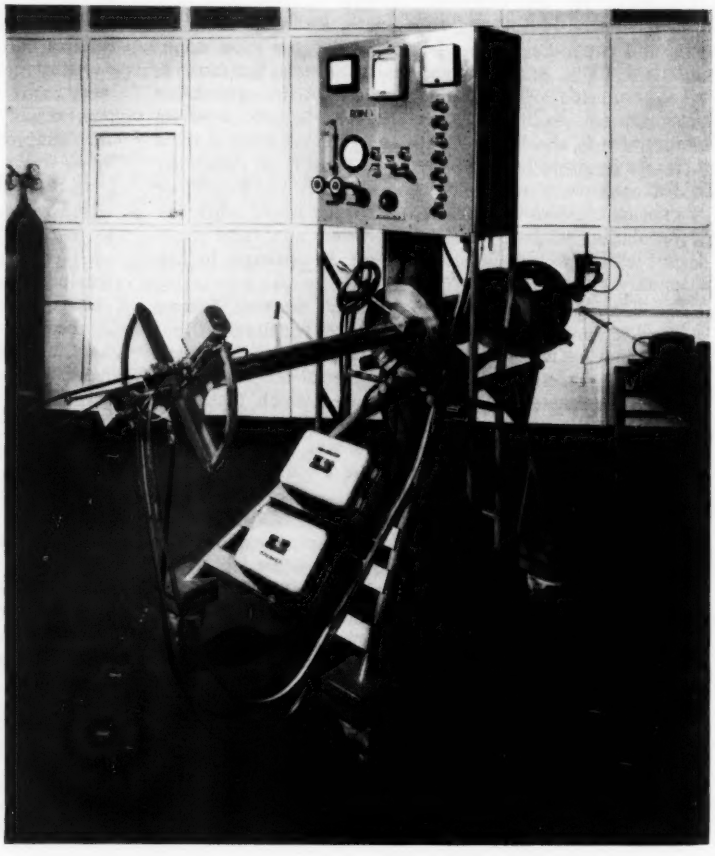
The method of inspection is to visually examine the outside weld profile which must be to an acceptable standard. Experience has proved that a very good indication of the inside weld profile can be assessed from the shape of the outside surface. Visual inspection is followed by pressurizing each tube in turn with a leak searching gas and then examining the outside for leaks with the aid of a very sensitive leak probe.

As no suitable inert-gas welding torch was available on the commercial market for making welds of this type, a torch had to be developed and with the experience gained after much trial and error the stringent requirements were met. The entire control unit—with the exception of the welding rectifier—has been specially developed. Although a special cutting-out tool was devised, its use was never found to be necessary.

Although the machine is automatic, owing to the importance of the project and the critical working conditions it was considered necessary to institute a daily routine of qualification inspection to ensure that all welds are made under identical conditions.

When the development of the joint and welding conditions had been established a full scale mock-up was built to ensure that welds made under laboratory conditions could be reproduced in the workshop. This exercise proved profitable because, apart from welding, much was learnt with regard to such other details as methods of tooling for the stub preparation, element tube manipulations, practical application of resistance preheating and post heating, and also a thorough appreciation of the meticulous care and precision that is required to make successful welds of this kind. Without going into a full discussion of the merits of the chosen technique a predominant advantage is the absence of the stresses which would normally arise during the cold working of the expanded type of joint. The avoidance of stresses in the base material helps to prevent corrosion defects. Secondly, there is an increase of ligament efficiency achieved because the tube plate holes are to the size of the tube inside diameter and not the outside diameter as would be the case with expanded tubes. Certain equipment described in this article is the subject of patent applications.

When complete the header with its tube assembly was stress relieved in an argon atmosphere. Pressure tests have now been successfully completed.



The bore welding equipment developed by Foster Wheeler.

Sintered Aluminium Powder *as a Canning Material*

By C. BRIDOUX, J. KAUFFMAN, P. THOME (*C.E.A.*) and H. FOULQUIER
(*Indatom, on attachment to C.E.A.*)

SINTERED aluminium powder offers interesting possibilities for use as a canning material in organic-cooled reactors. Its low neutron cross-section and good mechanical properties make it attractive for operation at mean temperatures of about 500°C[1, 2, 3]. However, its application is dependent upon a number of conditions being satisfied, concerned with the sealing of the fuel elements and the behaviour of the material at temperature, in terms of mechanical stability and compatibility with fission products.

This article does not deal with the physical properties of SAP, which have been the subject of several publications, for example, the Danish report from Risö by Hansen *et al*[7].

Welding Studies

SAP can be formed by hot pressing or by drawing, its physical characteristics precluding all processes involving fusion, if the inherent advantages of the material are to be retained. In fact SAP is totally destroyed at the fusion temperature of aluminium, the oxide films being broken by the fusing metal and the particulate characteristics disappearing. Considerable de-gassing takes place and all that remains is a mass of aluminium full of impurities and porosities.

An impervious joint cannot be achieved by fusion welding processes and at the same time brazing is impracticable except by using certain delicate techniques which are of no interest in the context of nuclear reactors. The processes which seem suitable for the material are basically welding by forging, ultrasonic welding and flash welding. The study, reported here, is concerned solely with the last of these.

Equipment

The principles of the process[4] can be seen in Fig. 1, which is a diagrammatic representation of a butt welding machine. The jig comprises two dies or clamps holding the pieces to be welded, one of which is movable and is carried on a platen which is controlled by a mechanical system designed to force the pieces together under great pressure. Power is supplied by a step-down transformer capable of delivering a very high current (20 000-35 000 amp on the machine used) at a low voltage (4-6 V) determined by tappings on the primary. Its secondary winding, comprising a single turn only, is connected to the two clamps, the jaws of which are of high conductivity metal (copper, or copper-alloy).

For flash welding, the current is first established with the pieces in imperfect contact at the proud surfaces; the current concentrates at the contact points which heat up and volatilize almost instantaneously. The pieces are brought together at a closely controlled speed so that the irregularities on the surface are progressively brought into contact, melt and fly outwards in a shower of sparks. The speed of advance of the carriage must be increased so that the shower steadily intensifies. The process ends with a rapid upsetting of the material under high pressure and the cutting of the current at the start of the forging operation.

For the flash welding of light alloys secondary currents of large magnitude are necessary because of the low resistivity of the material and its excellent thermal conductivity. As a result the welding equipment must be capable of developing very high currents instantaneously, the flash time must be short—an indispensable condition in view of the good thermal conductivity, and again for the same reason and also to avoid oxidation the upsetting process must be extremely rapid.

The requirement for regular, short flash times makes the employment of automatic machines essential. The equipment used in tests at Saclay is of conventional design and was supplied by S.A. Electroméchanique of Brussels. With a 250 kVA power output, it has three tappings for control, permitting the production of the following secondary outputs: 24 000 amp at 4·4 V, 29 000 amp at 4·9 V, 35 000 amp at 5·4 V.

The oil-pneumatic control of the mobile table provides on the forward movement for an initially slow motion followed by acceleration, during which the flashing takes place, and a very rapid movement for forging the weld. Retraction is at the maximum speed possible.

The principle of operation is simple (Fig. 1b): an hydraulic shock absorber A, is mounted in opposition to the pneumatic cylinder B, providing the drive to the mobile platen C; the displacement speed of the table is controlled by the adjustable leak from the escape valve in the shock absorber. A cam

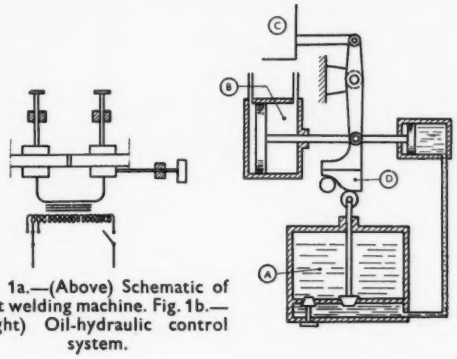


Fig. 1a.—(Above) Schematic of butt welding machine. Fig. 1b.—(Right) Oil-hydraulic control system.

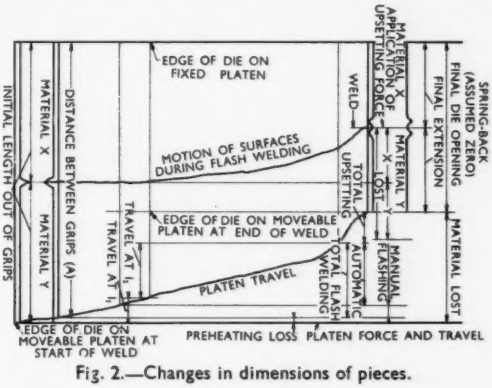


Fig. 2.—Changes in dimensions of pieces.

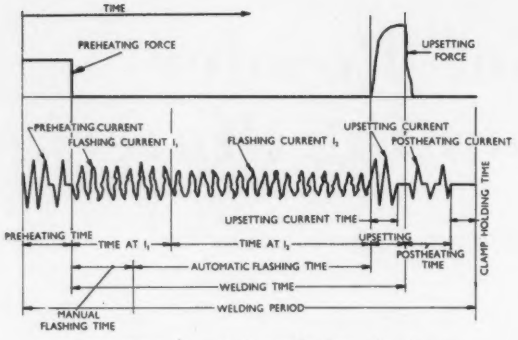


Fig. 3.—Current variation against forging thrust.

connected to the movement of the table controls the progressive opening of the valve which is complete at the moment of upsetting. The speed of approach depends little on pressure while that of upsetting is a direct function and is proportional to the length of the upsetting stroke.

It is recognized that the operation of this apparatus is rather unstable[4] even when allowance has been made for possible variations in the viscosity of the oil and friction of the platen and the control mechanisms. This could explain a certain spread in the mechanical test results on the welded samples.

The voltage is applied by means of a push-button switch, linked with the mechanical controls. The current is automatically cut at the end of the welding cycle by a device which measures the duration of the current from the beginning of the upsetting process.

Welding Parameters

It is convenient to discuss the influence of the variables on the process by referring to Figs. 2 and 3 which are the classical curves showing current variation against the forging thrust and the change in dimensions of the pieces. In the particular cases considered the diagram can be simplified as preheating is not required.

The quality of the welds has essentially been determined in terms of tensile strength, the form of the weld and test pieces being shown in Figs. 4 and 5. The tests were carried out on SAP 895 and SAP 865 supplied by S.A. pour l'Industrie de l'Aluminium of Switzerland.

The welding parameters are fairly numerous and mutually dependent. To avoid a too laborious research programme, account was taken of recommendations for the welding of light alloys from which acceptable values could be established. These values served as a point of departure for the research into optimum conditions and are set out below:

Overall movement	18 mm
Upsetting stroke	5 mm
Speed during flash welding	7·5 mm s
Power	35 000 amp (445 amp/mm²)
Forging thrust	3 000 kg
Length of upsetting period	3 cycles
Final distance between dies	2 mm

Influence of length of sparking stroke. The total travel of the platen is equal to the sparking stroke plus the upsetting stroke. Because of the thermal properties of the material it is necessary to burn an appreciable quantity of the metal away to attain a sufficiently high temperature at the point of welding. When sparking is too prolonged, overheating would appear to be the reason for the deterioration of the mechanical properties. For a specimen 10 mm diameter a sparking distance of between 7 and 15 mm (total stroke 12-20 mm) is suitable (Fig. 6).

Upsetting stroke. During the measurements a total stroke

Fig. 4.—Samples for welding.

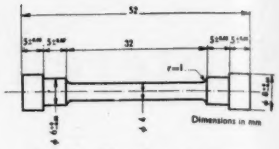


Fig. 5.—Tensile specimens.

of 13 mm has been maintained. The upsetting action results in the expulsion of metal during the forging operation; for short upsetting strokes there is a wide scatter in the test figures on SAP 895 and this scatter is certainly due to insufficient extrusion of the zones oxydized during sparking. In view of this an upsetting stroke of between 4 and 6 mm has been adopted. It should be noted that a variation in this stroke entails a modification of the speed of upsetting and also that the metal is strongly resistant to the forging operation.

Speed of approach of the platen (speed of sparking). It is necessary to maintain continuity of sparking; if the approach rate is too slow, only intermittent sparking occurs and it is insufficient to heat the parts; with excessively high speeds sticking occurs before forging can begin. Within a very wide range of speeds, however, no influence on the quality of welds has been observed. The optimum speed is found to lie between the limits of 5 and 15 mm s, values very different from those necessary in the upsetting process where speeds in the region of 500 mm s are involved.

Upsetting period. The short circuit current must be sufficient to allow proper forging in the presence of fairly vigorous cooling. If the period is too long, the metal is needlessly overheated and crushing of those parts in the vicinity of the weld results, a phenomenon which is also influenced by the final separation of the die jaws. Using the values of the various parameters already discussed an upsetting period of two cycles is sufficient. If this is increased up to four cycles one detects a small variation in the final results, whereas for more prolonged periods the properties appreciably deteriorate (overheating).

Final separation of the dies. The final separation of the dies influences the transient thermal conditions of the pieces at the time of forging and also the risk of buckling. During the preliminary work, the jaws were adjusted so that alignment was kept to better than 0·1 mm. Tests indicate (Fig. 7) that if the final separation is too great forging is inadequate in the welded zone and is accompanied by overheating of the zones near the weld. For pieces with dimensions similar to those studied, a final separation of 2 mm was desirable.

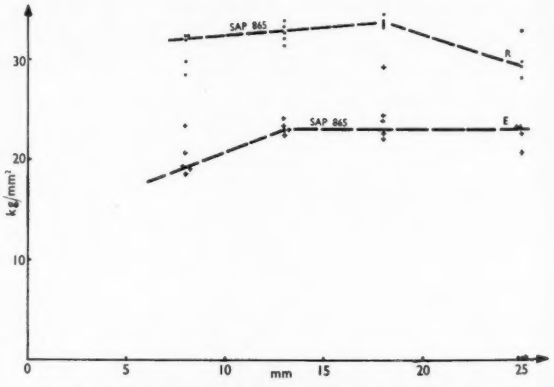


Fig. 6.—Tensile strength and proof stress as a function of sparking stroke.

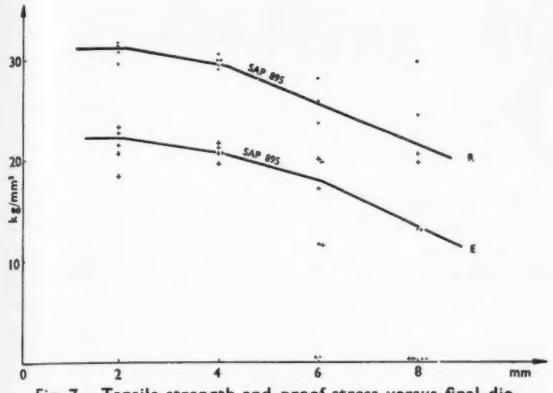


Fig. 7.—Tensile strength and proof stress versus final die opening.

The optimum conditions for welding for a specific power of 445 amp/mm² and a forging thrust of 3 000 kg are as follows:

Overall stroke	18±2 mm
Length of upsetting stroke	5±1 mm
Speed of sparking	7·5 mm/s
Period of upsetting	2-4 cycles
Final die separation	1-3 mm

Under these conditions tensile tests give, with slight variations, for SAP 895 a UTS(R) = 30·5±0·5 kg/mm² and a proof stress (E) = 21±2·0 kg/mm², whilst for the base material R = 33·4±0·5 kg/mm² and E = 22·4±0·6 kg/mm².

The strength of the welded test pieces as a function of temperature is shown on Fig. 8. Here the values are superior to those which have formerly been found with a sample of SAP of the same composition.

Cartridge Fabrication

The extrapolation of these results to the welding of end caps does not present any great difficulties. The simplest scheme, using an end cap as in Fig. 11a, is not very suitable to cartridge manufacture, as in practice material thrown out by sparking and forging remains locked up in the can together with a significant volume of gas. The high temperature subsequently causes excess pressure in the entrapped gas.

The method used to overcome this is shown in Fig. 11b. The end cap is in the form of a plug (item C) which is counter-bored and inserted into the can so that its edges are flush with those of the can. An auxiliary piece, item B, with a counter-bore to match that of item C forms the other electrode. Upon welding, items A, B and C are fused together as shown in Fig. 11d, the materials thrown out being trapped between the two counter-bores. Finally item B is machined as shown and the counter-bore cleaned out. Experience has shown that if the welds are defective there is a tendency for the joint to open between items A and B leading to low mechanical strength and in a large proportion of cases to actual leakage. To eliminate this trouble it is essential to provide good electrical contact and mechanical fixing between items A and C so that these units behave as a single mass during the welding operation. This can be achieved in a number of ways, two of which are shown in 11c. The can and plug can be threaded or a conical plug used.

Tests on the strength of the fittings by bending show the weld to be good. In the case of screwed plugs, failure first becomes evident at the bottom of the thread due to the notch effect and the mechanical strength is that of the can. With the methods and end conditions described, a great number of end caps have been welded on and complete cartridges closed with excellent results as shown by helium leak tests and tests on mechanical strength.

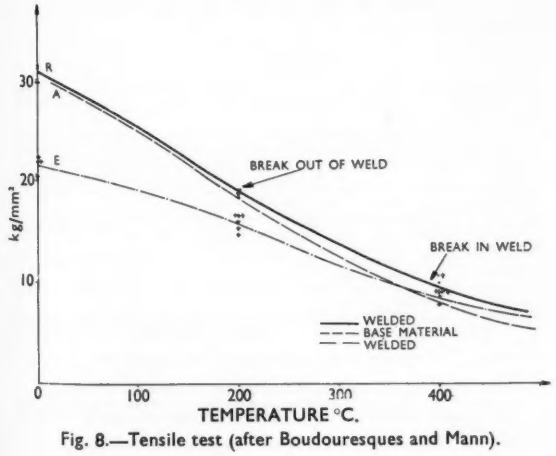


Fig. 8.—Tensile test (after Boudouresques and Mann).

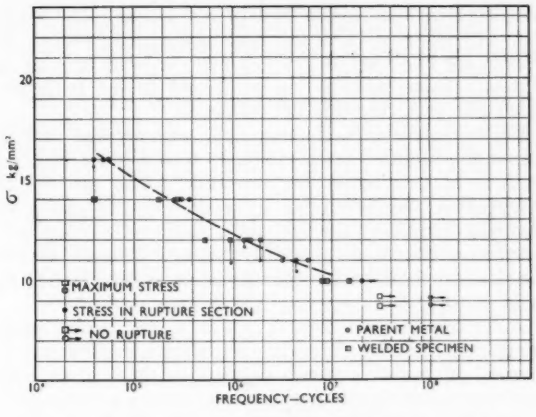


Fig. 9.—Fatigue tests on sintered aluminium by rotation bending.

Use of SAP as a Canning Material

The use of SAP as a canning material raises three essential problems which are already understood or are in the process of active consideration. These are: diffusion of fission products into SAP, the appearance of postules and cracks from prolonged heating giving rise to leakage paths, and the implications of the use of SAP in "unsupported tubes" (i.e., where the fuel provides no mechanical strength) where the bad ductility of the material is important. This has led to studies on the instability of tubes subject to external pressure.

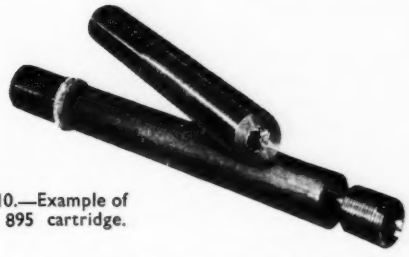


Fig. 10.—Example of SAP 895 cartridge.

Schleicher and Weber[3] have reported on a series of experiments made at 400 and 500°C in which the size of the diffusion zone was measured between various SAP materials

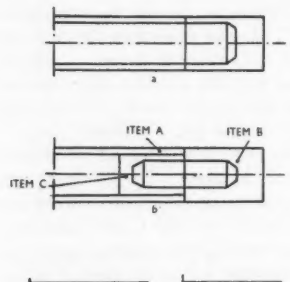


Fig. 11.—Development of fuel element end cap welding.

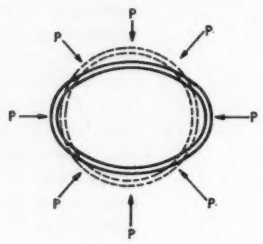
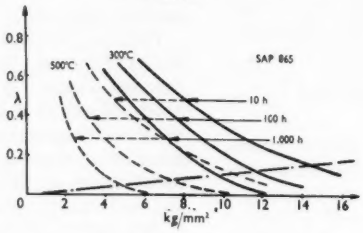


Fig. 12.—(Left) Effect of creep.

Fig. 13.—(Below) λ against applied stress.



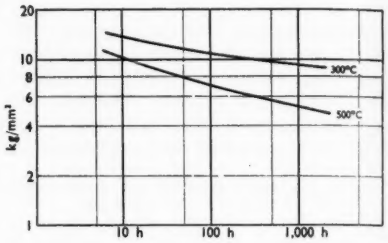


Fig. 14.—(Above) Creep time before buckling.

and aluminium containing 10% of rare earths. The formation of postules on SAP has been observed by Evans[10] on treating for one hour at 593°C a material with 10% oxide content. These postules are attributed to the hydrogen which will be occluded in the material.

The behaviour of fuel elements in unsupported cans at a given temperature, when submitted to a uniform external pressure is a criterion for selection. The use of an unsupported can precludes by definition the can ever becoming bonded to the fuel and subsequently being subjected to stresses due to thermal cycling. The problem is therefore confined to the calculation of instability due to creep.

Under certain conditions, it can be solved by the usual strength of materials formulæ. In effect the difference in the radii of curvature of two adjacent longitudinal sections in a beam under applied forces can be written as a function of the ratio of the relative elongation $d\epsilon$ of fibres subject to an increment of stress $d\sigma$, and this is independent of the phenomena which make up this ratio. Bernoulli's hypothesis remains valid if the bending stresses remain small compared with the direct stresses.

The ratio $d\sigma/d\epsilon$ is designated by E_t' and is applied to the production of stress-strain isochrones; these curves can be presented in a fairly simple analytical form. The function adopted is written as: $\epsilon = \sigma/E + A \exp(n\sigma)$. In this two numerical coefficients appear, A and n which can be determined by measuring for two values of σ the corresponding elongations ϵ at the end of a given period τ. Carlson and Schwope[6] having verified experimentally the area of validity of this method have used in their calculations an expression in which the time τ appears.

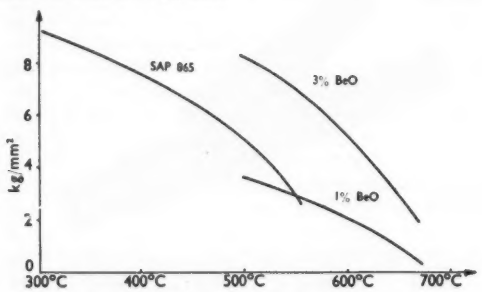


Fig. 15.—Stress for buckling after 1 000 hr creep.

		τ = 10 h		τ = 100 h		τ = 1 000 h	
	E	σ0·2	σ0·5	σ0·2	σ0·5	σ0·2	σ0·5
θ = 300°C	5 500	11·5	15·1	10·1	12·5	8·5	10·5
θ = 500°C	3 700	6·9	9·7	4·9	6·7	3·2	4·3

We have plotted (Fig. 13) the ratio:

$$\lambda = E_t'/E = 1/(1+EAn \exp(n\sigma))$$

as a function of σ at τ = 10 h, 100 h, 1000 h for two temperatures 300 and 500°C.

The values of the coefficients A and n have been calculated starting off with the figures given above taken from the creep curves in references 1, 7 and 8.

The critical buckling stress at τ = 10, 100, 1000 h is determined in the case of circular tubes by the intersection of the curves in Fig. 13 with the straight line expression

$$\sigma_{cr} = \frac{\lambda E}{1-\theta^2}\left(\frac{e}{\phi}\right)^2$$

where e and ϕ are the thickness and diameter respectively of the tube. The results obtained are given in Fig. 14. Fig 15 represents the critical buckling stress at 1000 h as a function of temperature for tubes 19·6 mm diameter with a wall thickness of 1·5 mm in SAP and in beryllium containing 1% and 3% oxide calculated by the same method[9]. These curves indicate that over the range of temperatures between 400 to 500°C the creep strength of SAP is comparable with that of beryllium.

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Welding Stainless Steels

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ONE of the most useful ways of illustrating the effects of complex composition on the metallurgical structure of stainless steels, a term which covers a wide range of materials is given by Schaefflers[1, 2] diagram (Fig. 1). This indicates the effects of nickel, carbon and manganese, the main elements promoting the formation of non-magnetic austenite phase, expressed as nickel equivalents according to the formula along the vertical axis of the diagram, while chromium, molybdenum, etc., the elements promoting the stability of the magnetic ferrite phase, are plotted, according to the formula along the horizontal axis, as chromium equivalents. From the position of a point corresponding to a given commercial alloy the phases present in the as-welded state can be deduced and also information obtained relating to the alloy's weldability.

The diagram indicates that the comparatively low alloyed steels are hardenable as they are contained in the " martensitic field " of the diagram. Strictly, only a small proportion of compositions in this field can be classified as stainless, as more than 11% of chromium is necessary to give a continuous film of chromium oxide and it is this film which is responsible for the improvement of the corrosion and heat resistance. As the total alloy content increases beyond the martensitic field, the equilibrium phases of austenite and ferrite become more stable and the alloys cease to be quench hardenable. Steels with a relatively high level of nickel, carbon and manganese become fully austenitic, while those with a predominance of chromium, molybdenum, etc., tend to be fully ferritic. There is also an important field of " duplex " austenitic-ferritic steels indicated as A+F.

Although the fully austenitic and the partially austenitic stainless steels are generally more suitable and convenient as regards toughness, corrosion resistance, creep strength and weldability, the other grades of the martensitic and ferritic types also have potentialities, which can occasionally be exploited by the techniques of lining and cladding.

MARTENSITIC STEELS

The deposition of weld metal by any fusion welding process is associated with rapid rates of cooling, which can vary from conditions comparable to water quench when on base metal of considerable heat capacity to relatively slow air cooling, according to variations in preheat, speed of travel and rate of heat input associated with the welding procedure. In general, however, with air hardenable compositions in the martensitic area an increase in hardness and a loss in ductility is bound to result in the welds and the heat affected zone of the base metal during a welding operation. For this reason it is desirable, whenever one of the components of a joint is in the martensitic area, to preheat the materials before welding. When both the weld and the base metal are hardenable this becomes even more necessary, and the welding operation is usually followed by a post heat treatment designed to relieve stresses and impart ductility to the joint.

Some typical temperatures of preheat and post heat treatment are given in Table 1[3]. In general, the preheat temperature required increases with the sum of chromium plus nickel equivalents within the martensitic field, while the post heat temperature mainly depends on the value of the chromium equivalent. When more ductile austenitic electrodes are used for welding hardenable steel, the preheating precautions can be slightly relaxed.

It should be noted that the functions of preheat are many sided, it:

(a) Reduces the rates of cooling and consequently the severity of local hardening,

(b) Assists in reducing thermal strains,

(c) Promotes wider yielding and reduces stress concentrations.

The details of the application of preheat are, as a result, of considerable importance. The preheat must be applied evenly, to prevent local leverage effects associated with a localized source of heat; it should be allowed to soak through until the temperature on the side opposite to the source has attained the desired level; the preheated band should extend to a width of at least six inches on each side of the weld, or three times the thickness of the plate, whichever is greater. This gains in importance with the increase of thickness and rigidity of the assembly, when all strains tend, for practical purposes, to be exclusively concentrated in the reduced section of the weld. The neglect of the above precautions may lead to martensitic cracking.

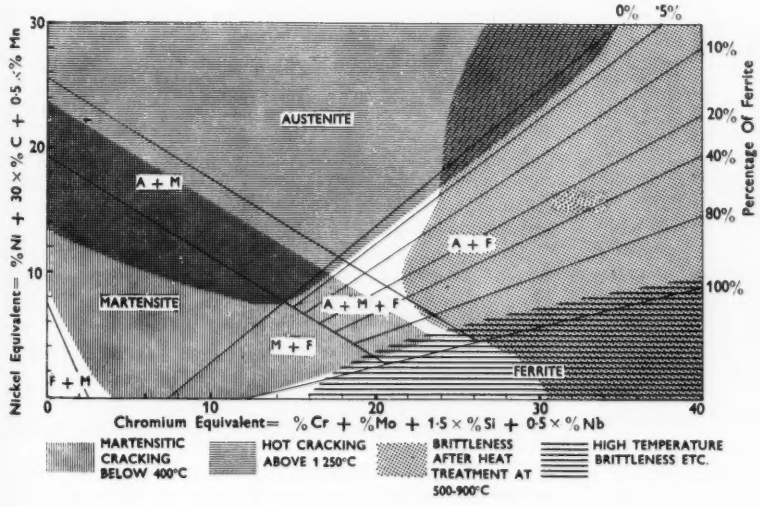

Fig. 1. — Constitution diagram for stainless steel welds with approximate regions of defects depending on composition and phase balance.

TABLE 1(a). Preheating temperatures for welding hardenable steels.

Cr eq.+Ni eq. of steel	Temperature, °C	En steels to B.S.970 : 1955
Cr eq.+Ni eq.<4 ..	No preheat	1A, 1B, 2A, 2B
4<Cr eq.+Ni eq.<9 ..	100–150	2, 2C, 3, 3A, 3B, 3C, 14A, 14C, 36C
9<Cr eq.+Ni eq.<14 ..	150–250	4, 5, 6, 7, 8, 12, 13, 14B, 15, 16, 17, 20, 29A
14<Cr eq.+Ni eq.<18 ..	250–350	9, 10, 11, 18, 19, 30A, 43
18<Cr eq.+Ni eq.<22 ..	350–450	40C
22<Cr eq.+Ni eq.<26 ..	200	Austenitic—martensitic
26<Cr eq.+Ni eq.< ..	No preheat	Austenitic

TABLE 1(b). Post-heat treatment temperatures for hardenable steels

Cr eq. of the steel	Temperature, °C
Cr eq.<2..	650°C
2<Cr eq.<6	700°C
6<Cr eq.<10	720°C
10<Cr eq.<24	780°C
24<Cr eq.	Above 850°C if necessary

Martensitic Cracking

Martensitic cracking which can take several forms, occurs at comparatively low temperatures, i.e., below the range of stability of austenite. The localized hardening, associated with volume expansion, is aggravated by external stresses and the presence of hydrogen, which can build up a high pressure in defective regions, thus causing delayed cracking. For this reason certain low alloy steels are frequently post-heat treated directly after welding at temperatures of 600°C for half an hour if the final heat treatment has to be delayed.

The area likely to be affected by this form of cracking is marked on the diagram. Some hardenable steels with higher carbon and nickel content can also exhibit increased tendencies to hot cracking during solidification; such cracks are usually more heavily oxidized and may trigger off propagation of martensitic cracks from the notches.

Applications

The martensitic stainless steels of the 12% chromium and 18 Cr/2 Ni type have so far seen little service in nuclear engineering. Their main attraction is their high strength

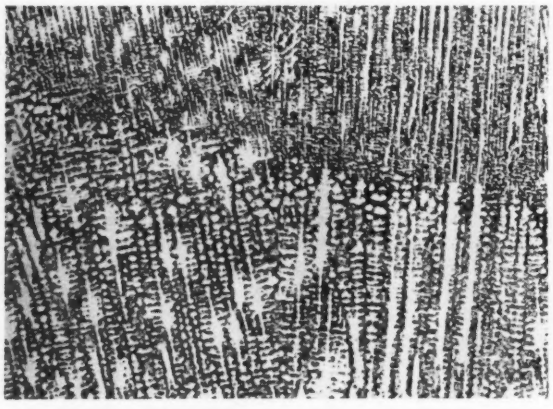

Fig. 2.—A fully austenitic weld deposit. Boundary between two superimposed runs. Coarse grained dendritic structure. Etched 5% oxalic acid electrolytically.

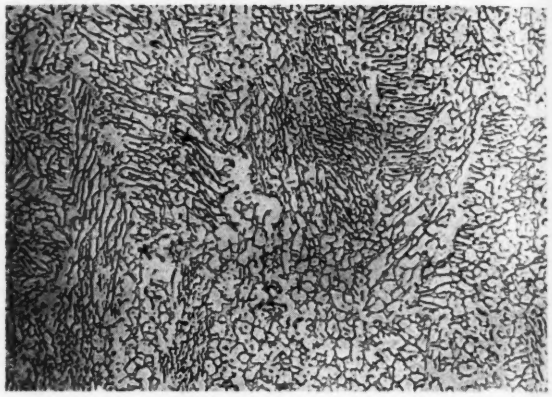

Fig. 3.—A "Duplex" austenitic ferritic weld with 22% of ferrite in a continuous network.

which can be varied by heat treatment and makes them eligible for moving components of machinery. Their surface resistance to wear and scaling in various atmospheres leads to their choice as a lining and cladding in the petroleum industry.

Residual addition of carbide forming and creep strengthening alloying elements, may in due course widen their scope, as an extension of the low alloy air-hardenable creep resisting steels, like the 1 Cr/½ Mo, 2¼ Cr/1 Mo and 5 Cr/½ Mo grades which with variations containing Ni, V, etc., are more widely used for hot containment. One may add at this stage that the beneficial effects of Ni on the impact values and the lowering of the brittle transition temperatures, a factor affected adversely by irradiation, may lead to the evolution of special creep resisting materials more suitable for reactor pressure vessels. The coexistence of hot-cracking and martensitic cracking may, however, become a matter of concern for the welding engineer, but this point will not be elaborated here.

AUSTENITIC AND FERRITIC COMPOSITIONS

The fully austenitic region on the diagram comprises such compositions as 18 Cr/13 Ni/Nb, 17/12/3 Mo, 25 Cr/20 Ni, etc. Although the austenitic area offers indisputable advantages with respect to corrosion, creep strength, ease of forming and, with the fully austenitic higher Ni alloys, an increased chance of avoiding stress corrosion, all these materials have a tendency to hot cracking and micro-fissuring in welds under conditions of more severe restraint. The composition areas likely to lead to hot cracking are also indicated on the diagram, and the coarse grained dendritic structure of fully austenitic welds is shown in Fig. 2.

In contrast, welds in the "Duplex" field which includes the most popular austenitic steels like the 18 Cr/8 Ni, 18 Cr/10 Ni, 25 Cr/12 Ni with or without Mo, Nb, Ti, are very resistant to hot cracking (Fig. 3).

The welds containing residual ferrite therefore, form the core of the most popular stainless compositions for service at room temperatures. However, for certain applications in the medium range of temperatures (500-900°C), the grades with higher ferrite content involve the risk of gradual loss of ductility and impact resistance as a result of the precipitation of minor brittle constituents like sigma phase. The area likely to be affected in this way is again shown on the diagram.

This leaves a comparatively small region of safer compositions with lower ferrite, to which many of the reputable

austenitic electrodes are confined, with the exception of types which are designed for welding dissimilar materials. These usually have a higher ferrite content but are expected to be within the safer field after dilution.

To complete the survey of the Schaefflers diagram the ferritic high chromium steels should be mentioned. This field contains compositions like the 17, 20, and 27 Cr types.

The useful heat resisting properties even in sulphur-polluted atmospheres, make these steels suitable for furnace equipment and other applications where thermal shielding and not hot strength are the primary concern.

While these steels and welds are free from hot cracking they have disadvantages such as:—

(a) Low impact resistance, because of higher brittle transition temperature.

(b) Low ductility in the heat affected zone and the welds, due to a phenomenon associated with the coarsening of grains when reheated (as in welding) above 1 150°C.

(c) Embrittling precipitation phenomena at around 475°C and in the sigma range.

Hot Cracking of Austenitic Steels

In the present state of knowledge, the evidence tends to suggest that cracking both in the weld and the heat affected zone of the austenitic base metal is due to two correlated mechanisms of intergranular weakness. Although in the first stage, the shrinkage of the fully austenitic welds or overheated base material may lead to residual liquation of the segregated intergranular regions, thus causing hot cracking in single bead welds and the formation of shallow surface fissures in the base metal, it appears that even if this mechanism does not become effective, the subsequent stage of strain-assisted precipitations may affect the relative hot strength of the grains and grain boundaries.[4]

This leads either to propagation of cracks formed in the first stage, or their initiation in weaker grain boundaries by the second mechanism, in the last stages of multi-pass welding and/or during subsequent heat treatment or by thermal fatigue in service[5].

Hot cracking in the fully austenitic welds is activated mainly by the first mechanism of intergranular liquation while underbead cracking in the heat affected zone of thick austenitic material mainly depends on the second mechanism and will be discussed later. The hot cracks and fissures usually run along the lines of local temperature gradients, perpendicular to the isothermal lines of the weld ripples (Fig. 4).

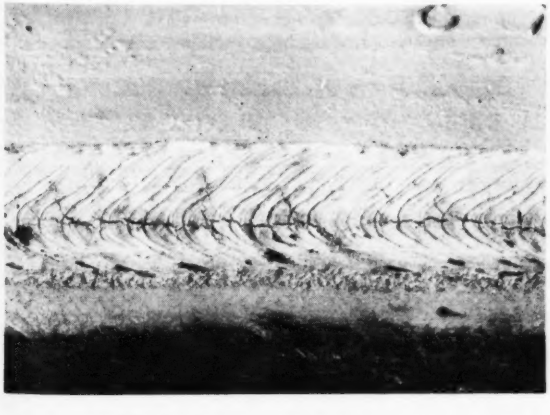

Fig. 4.—A network of coarser and finer hot cracks in a fully austenitic weld. The cracking is aggravated by pick-up from a nickel-copper alloy which forms one of the members of the fillet.

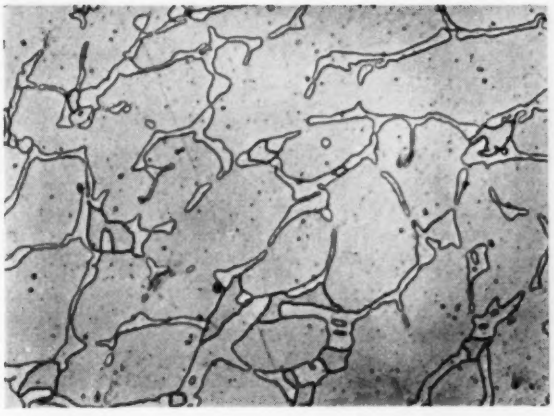

Fig. 5.—Austenitic ferritic Cr-Ni-Mo base material with ferrite (darker) and a nearly continuous network of sigma phase formed at temperatures between 500°-800°C on prolonged cooling. Etched in 5% oxalic acid electrolytically.

In this connection factors which tend to intensify the thermal gradients, shrinkage effects and excessive penetration should be avoided. It is therefore advisable to use relatively smaller gauges of electrodes, the lowest convenient currents and narrow weave techniques. Any design features which amplify distortion and increase restraint should be altered. Thus it is preferable to replace fillet welds with unrestrained butt-welds and wide angle unbalanced single V preparations with narrower, balanced and less voluminous double-U preparation, particularly when welding thicker material.

When using fully austenitic electrodes which are much more prone to cracking than those containing residual ferrite, the coatings of the basic lime-fluorspar type are preferable. They ensure better extraction of impurities, such as S and P, lower silicon contents and a higher degree of deoxidation.

Although a slight preheat may be beneficial in reducing "start porosity," it is not of any help with the problem of hot-cracking and in some cases accidental temperature fluctuations (in preheating) may be even deleterious. Whenever possible, frequent tacking at intervals of four inches should be applied and the strains and distortions balanced by skipping and back-step welding techniques, trying always to advance in the direction of the less rigid end in straight beads with a minimum of weaving. If crater or start cracks are observed in more restrained preparations, they should be at once chipped and repaired to stop their propagation.

Sigma Phase Formation

Sigma is an equilibrium phase of certain stainless steels and the approximate field of compositions likely to become embrittled by reheating into the medium range of temperatures has been pointed out during the discussion of the Schaefflers diagram. Sigma formation is promoted by the increase of chromium equivalents.

Although for the majority of applications at room temperature the danger of embrittlement is of limited importance, the time spent in the harmful range of temperatures being comparatively short, the applications involving heat treatment after welding or during service have to be considered critically in this respect. Fig. 6 (a) shows a cast specimen fractured with a negligible angle of bend due to the dense network of sigma phase formed as a result of slow cooling of a solution treated steel with a high proportion of ferrite. The corresponding micro-structure is shown in

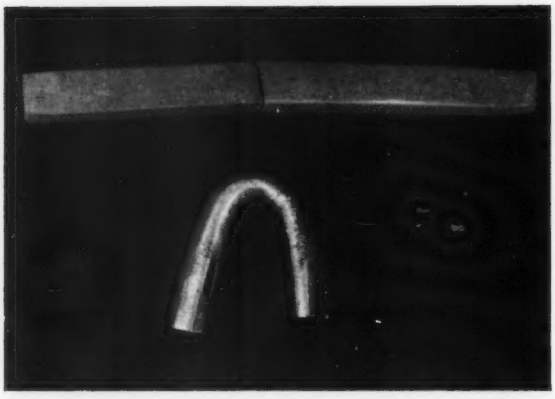

Fig. 6. (a) (above)—Bend specimen from the embrittled base metal in Fig. 5, containing sigma phase, with a negligible angle of bend before fracture. (b) (Below) The same base material as in Fig. 7, showing a restored ductility after removal of sigma phase.

Fig. 5. Fig. 6(b) demonstrates the ductility restored by a solution treatment at 1 050°C followed by more rapid cooling, which destroys sigma phase (see Fig. 7).

A reasonable compromise to reduce sigma phase in welds while preserving freedom from hot-cracking is to use electrodes giving controlled ferrite content (white field).

Corrosion Resistance

Although the continuity and adherence of the chromium oxide film is of basic importance in improving corrosion resistance, the additions of alloying elements like nickel molybdenum and the so-called " stabilizers " like niobium and titanium, have further favourable effects depending on the corrosive environment.

In spite of that, however, the wrong choice of material and careless handling of the surface is likely to cause occasional corrosive attack and a serious shortening of the life of a plant.

There are several modes of corrosive attack.

(a) General surface corrosion by strong acids.

(b) Local pitting, which may lead to perforations in media containing chlorides, sulphates, and stronger organic acids.

(c) Intergranular corrosion associated with local depletion of chromium near the grain boundaries as a result of precipitation of chromium carbides.

(d) Stress corrosion by selective attack in the more stressed areas, especially in the presence of chlorides.

(e) Other forms of preferential attack associated with the heat treatment of the steel and the nature of the corrosive medium.

These difficulties are usually overcome by a thorough study of past experience and advance experimentation in conditions closely reproducing the actual service.

The basic care for the surface of any stainless assembly, can be summarized as follows:—

(1) Grinding and polishing operations should be done lightly without damaging the surface by overheating and local distortion.

(2) Avoid hammering, stamping and arc-striking marks on the surface in contact with the corrosive agent.

(3) Remove particles clinging to the surface as a result of grinding, crystallization or sedimentation in service. Their detrimental effect is associated with phenomena of " differential aeration," i.e., variations in the access of oxygen, which leads to corrosion in the less aerated areas (e.g. crevices).

(4) Possibly apply preliminary passivating treatment and use corrosion-inhibiting agents helping to build up protective films.

The bulk of chemical processing in the nuclear field can be adequately conducted in 18 Cr/13 Ni/1 Nb stabilized vessels, welded with partially ferritic electrodes of somewhat lower Ni content.

In certain more aggressive media containing fluorides topping up surface layers with 25 Cr/20 Ni-Nb electrodes proves advantageous. For the most adverse conditions possibly with chances of stress corrosion, the nickel base alloys with Cr or Cu, like Inconel and Monel offer a definite advantage.

Although stabilizers, due to their high affinity to carbon, suppress formation of chromium carbides and consequently eliminate intergranular corrosion, at times when the presence of radioactive corrosion products is to be reduced, residual elements like Co, Nb and Ta may have to be avoided. In such cases lower carbon steels and the application of solution treatment at 1 050°C may become necessary, even if this approach is understandably less popular.

Welding Dissimilar Metals

As would be expected, a modern designer usually chooses in collaboration with the steelmaker, materials particularly suited to each section of the plant, taking into account the prevailing temperatures and corrosive effects and not forgetting the problems of weldability. In this context it is intended to discuss some difficulties associated with dissimilar metals during welding and later in service.

The main difficulties and precautions associated with the compositions have already been outlined in the Schaefflers

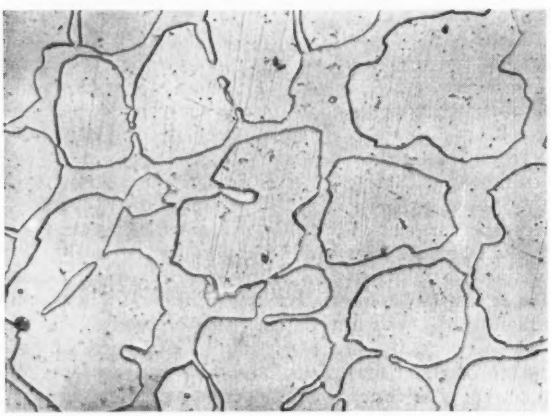

Fig. 7.—Base metal as in Fig. 5, after a heat treatment at 1 050°C followed by air-cooling. A dense network of ferrite, but with a complete absence of sigma phase.

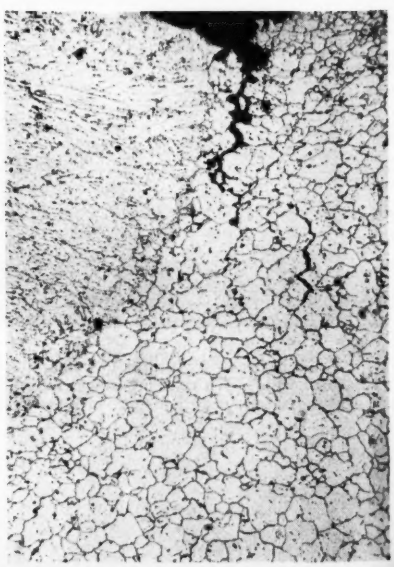

Fig. 8.—A crack in the heat affected zone of a 17 Cr/11 Ni/Cb material (347). The crack originates in the heavier component a few grains away from the weld boundary.

TABLE 2. Choice of electrodes for welding mild, low-alloy, and different grades of stainless steels in different combinations

Material			Mild or low-alloy steel	Martensitic stainless steel 12%Cr or 18Cr/Ni	Ferritic stainless steels 17Cr, 20Cr, 27Cr	Austenitic stainless steels containing Cr–Ni and minor alloying elements
	Preheat °C	Post-heat	Up to 250 Up to 700	Up to 350 750	200°C —	— —
Mild or low-alloy steels	250	700	(1) Ferritic low hydrogen electrodes	—	—	—
			(2) Austenitic *E, F, H*	—	—	—
Martensitic stainless steels 12Cr, 18Cr/2Ni	350	750	(1) Austenitic *E, F, H**	(1) Austenitic *E, F, H**	—	—
	—	—		(2) 12 Cr		
Ferritic stainless steels 17%Cr, 20%Cr, 27%Cr	200	—	(1) Austenitic *F, H**	(1) Austenitic *H**	(1) Austenitic *H**	—
			(2) 20%Cr	(2) 20%Cr	(2) 20%Cr and 27%Cr	
Austenitic Cr–Ni stainless steels with minor alloying elements	—	—	(1) Austenitic *E, F, H**	(1) Austenitic *E, F, H**	(1) Austenitic *H**	Austenitic electrode preferably with residual ferrite and better in corrosion resistance than the steels.
	—	—				

* Austenitic Cr–Ni stainless steel electrodes to BS 2926 : 1957 —Class *E*—20Cr–9Ni–3½Mo; Class *F*—25Cr–12Ni; Class *H*—25Cr–20Ni

diagram. In this case, however, the position of the diluted weld composition becomes significant, the dilution normally being defined as the percentage of picked up base metal in relation to the total volume of the weld.

In the cross section it becomes the percentage of the area of the remelted base metal, to the total area of the weld. For standard conditions of manual welding, the dilution is of the order of 25%, which can be expressed on the Schaefflers diagram by a graphical interpolation method as a proportional shift of 25% from the position of the nominal (undiluted) weld composition in the direction of the point representing the composition of the base metal.

If two metals of different compositions are in equal contact with a weld run, as in the root run of a butt weld between stainless and mild steel, then for the purpose of graphical interpolation, the two base materials can be represented by their average (midpoint). The choice of electrodes for "mixed welding" is usually safe, when the diluted weld composition is in the "white area" of the diagram; this is, however, not always possible for all service requirements. The position of the diluted weld on the diagram indicates the likely difficulties and the means of avoiding them, by choice of alternative materials or the application of routine precautions as discussed earlier.

For many simpler applications with temperatures below 400°C, and a comparatively less aggressive environment, there will be no further complications in service after the final inspection and commissioning of the welds. This particularly applies to designs where the duties assigned to particular metals are strictly separated as might be the case of an assembly where the mild steel on the outside fulfils the requirements of strength, while the internal stainless liner takes care of corrosion, the welds joining the two metals being situated in the less corrosive section of the assembly.

The electrodes eligible for some of the common combinations of stainless and low-alloy steels are given in Table 2 on the cross section of appropriate rows and columns. In a similar way the electrodes for welding different classes of nickel alloys to stainless and low-alloy steels are outlined in Table 3.

In the latter case a rule is followed that the electrodes for welding a nickel-base alloy to an iron base alloy should be always of the nickel base type. This is justified by the general experience that fully austenitic iron base alloys are usually more prone to hot-cracking than similar nickel base alloys.

For these applications the low carbon Inconel and Monel electrodes with additions of niobium are very useful and with a proper attention to cleanliness and precautions to reduce hot-cracking, satisfactory single and multi-pass welds can be produced. Such welds, however, will tend to show more porosity than good austenite stainless steel electrodes.

The use of the Inconel type of alloys offers improvement in the stress-corrosion, the impact resistance at subzero temperatures and reduces the effects of differential expansion; they are however less suitable for certain sulphur-polluted atmospheres.

Lining and Cladding

These applications can be considered as particular examples of welding dissimilar materials[6]. The backing material is usually a mild or low-alloy steel, while the

TABLE 3. Welding of nickel-base to iron-base alloys

Alloys	All stainless and low-alloy steels (For the hardenable steels preheat as in Table 1)	Nickel chromium alloys with iron less than 50% and Al, Ti and Mo residual	Nickel copper alloys (e.g., 63Ni–35Cu)	Nickel molybdenum alloys with or without Fe, Cr, W additions
All stainless and low-alloy steels (For hardenable steels preheat as in Table 1)	As in Table 2	80Ni–17Cr–Nb 60Ni–20Cr–Nb 65Ni–18Mo–15Cr–3W	60Ni–33Cu–3Nb Pure nickel 80Ni–17Cr–Nb	80Ni–17Cr–Nb 65Ni–18Mo–15Cr–3W
Ni–Cr alloys with iron less than 50% with or without Al, Ti, Mo	—	80Ni–17Cr–Nb 60Ni–20Cr–Nb	80Ni–17Cr–Nb 60Ni–33Cu–3Nb	80Ni–17Cr–Nb 65Ni–18Mo–15Cr–5W
Nickel copper alloys	—	—	63Ni–33Cu 63Ni–33Cu–3Nb	65Ni–18Mo–15Cr–5W 60Ni–33Cu–3Nb
Nickel molybdenum alloys with or without Fe, Cr, W		—	—	Appropriate matching electrodes, e.g., 68Ni–25Mo 65Ni–18Mo–15Cr–3W

surface consists of a relatively thinner layer of a stainless alloy. Normally the beads in partial contact with the mild steel are made with an electrode which "can take the existing dilution" without acquiring a martensitic structure. The 25/12, 20/9/3 Mo and 25/20 grades are suitable for this purpose. If, however, the final thickness of the stainless layer allows, it is advisable to top up the welds on the stainless side with two layers of a composition similar to that of the lining or cladding and thus better suited for the particular environment.

The attachment of stainless linings or fabrication of plant from stainless-clad materials is comparatively popular in the petroleum industry and certain less stringent applications in the chemical industry. Lining with more expensive nickel base alloys and the use of nickel and Monel clad materials may be desirable for a more aggressive environment. The fact that lined assemblies may involve a local attack with an increase in damage when the corrosive agents penetrate underneath, discourages the use of this technique in the nuclear field.

In certain conditions there is a danger of hydrogen generated in service penetrating underneath the lining and causing damage. For this reason, in thicker assemblies and in heavy forged dish sections, is sometimes expedient to deposit the stainless layers on the inside entirely by welding. This is of course easier by an automatic process, in particular when the level of preheat would make manual welding impracticable. The submerged arc process is quite suitable for such applications, provided the dilution, which in the case of a normal single wire method is of the order of 50%, can be reduced by suitable modifications of procedure to a more acceptable level.

Welding of Thick Stainless Steels

As mentioned earlier the welding of thick stainless steels (above $\frac{1}{4}$ in) introduces the danger of cracking in the heat affected zone close to the junction of weld and base metal, while at the same time appropriate attention must be paid to hot-cracking and sigma phase embrittlement in the weld.

The under bead cracking by the mechanism of strain assisted precipitations is comparatively common and is likely to arise in many creep resisting "super-alloys" of the iron, nickel and cobalt base type with appreciable amounts of carbide formers and with alloying elements introduced to promote creep resistance by a continuous series of precipitations in service. In the stainless range the Nb bearing steels (AISI-347) are more inclined to suffer from it than the plainer grades with Cr and Ni (AISI-308) and Cr/Ni and Mo (AISI-316).

The sequence of events leading to this trouble begins from the adverse conditioning of the heat-affected zone by reheating to temperatures above 1 200°C, followed by gradual critical straining due to shrinkage in contact with a rigid component. This finally leads to local low ductility at the temperatures of reheat by the neighbouring runs or in the subsequent thermal history[7, 8].

The crack initiation is rare in thicknesses below $\frac{1}{4}$ in for the Nb bearing (AISI-347) steels and the critical thickness is probably considerably greater for the Nb-free grades. Welds which by preferential yielding reduce the plastic strains in the heat affected zone reduce the risks of cracking[5].

The cracks initiate practically exclusively from the surface (Fig. 8) and can be therefore detected by die penetrant techniques. In the initial stages they may be only 1 grain deep and can be promoted by distortion of the surface, shallow intergranular liquation and surface attack.

Having chosen an ingot of adequate cleanliness (limited inclusion level), satisfactory composition, and having ensured that the hot working operations are conducted in the optimum range of temperatures, e.g., 1 050°C ± 100°C, the pipe should be machined to the required dimensions and again solution heat treated, as above, to eliminate work hardening. The material in this condition should be welded with preparations which will allow freedom of access for the welder and produce the minimum of shrinkage strains and localized stress concentrations.

Medium-size electrodes (8 or 6 gauge) are likely to give the best ductility in the welds, and should be deposited using a d.c. supply with the lowest convenient current consistent with the ease of manipulation and smoothness of bead contour. Weaving in excess of $1\frac{1}{2}$ x dia. of electrodes should be avoided, as this slows down the rate of straining and leads to a build-up of thermal gradients and uneven dilution effects.

For circular fillet welds, e.g., attachment of side branches, the direction of travel should be reversed at least every 180° to prevent the accumulation of strains caused by a hot-spot travelling in a full circle. The top beads should be moulded to ensure a concave smooth contour, which will reduce the amount of final grinding and the hazards of forming laps and surface imperfections at the toes of the welds, caused by uncontrolled chipping, hammering and other surface damaging operations in the last two layers of the weld. The deposition of the last bead in contact with the heavier component may be beneficial. The final contour shaping of the weld will be done by skilful grinding.

The grinding operation should take place before the stress relief and should include a band about $\frac{1}{2}$ in from the edge of the weld. This is advisable, because the top 0·005 in of the surface may have shallow imperfections mentioned previously, which can contribute to crack propagation and assist in a process of intergranular oxidation at the toe of the weld.

As the embrittling phenomena are promoted by the slower rates of straining in the medium range of temperatures[9], the post heat treatment should be comparatively slow 100°C/h up to temperatures of the order of 600°C, to relieve the stress-peaks and equalize the temperature gradients. After this a rapid stage of heating of 300°C/h should take place up to the temperature of the solution treatment, to be followed by air or furnace cooling[10].

The greatest danger of crack initiation and propagation during the heat treatment is in the heating-up stage, which is more likely to form tensile stresses and is associated with a material in a more critical state. After cooling from the heat treatment, with greater heat dissipation on the outside, the final stresses on the surface of piping are likely to be compressive.

The above precautions are derived from past experience with 347 base metal, in particular when the assembly incorporates many branch attachments. Whether the use of 304 or 316 steels in regions without branch pipes (main piping) can be completed without a post heat treatment or with a treatment at a temperature lower than 800°C requires further consolidation by experiment.

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9th March, 1961

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Nucleonics in Flight

Dr. N. M. Schaeffer, programme chairman, reports on the symposium sponsored by the North Texas section of the American Nuclear Society at Dallas, Texas, on March 28 and 29.

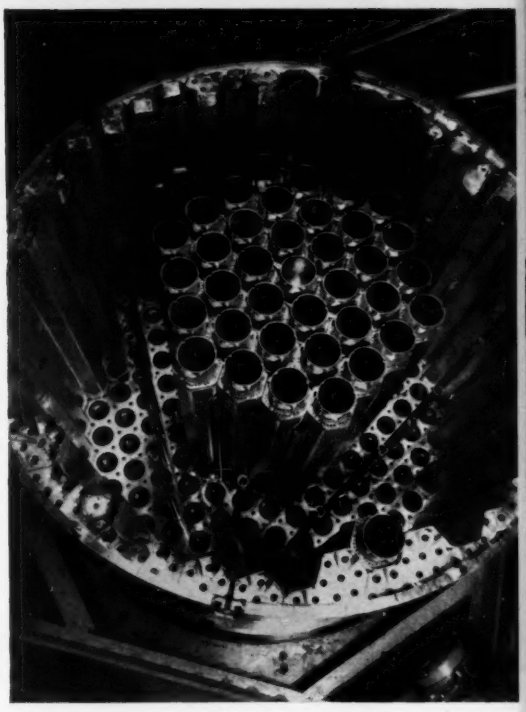


Fig. 1.—High temperature reactor experiment: a view of the core.

NUCLEAR-PROPELLED aircraft, rockets, ramjets, and space nuclear auxiliary power were principal topics for open discussion at the first symposium to be devoted exclusively to these systems in Dallas, Texas, March 28 and 29, 1961. The North Texas Section of the American Nuclear Society sponsored the meeting; over 300 representatives of 85 institutions were in attendance.

The opening session was chaired by Dr. M. C. Leverett, President of the American Nuclear Society and Manager of Development Laboratories of General Electric Aircraft Nuclear Propulsion Department, who introduced the two distinguished speakers, Brig. Gen. I. L. Branch and Mr. H. B. Finger, heads of the American programmes for nuclear aircraft and nuclear rockets, respectively.

In what has been remarked to be the most abysmal timing in the history of nuclear power, word was received of the cancellation of the nuclear aircraft programme shortly before General Branch gave the opening address.

General Branch deleted all mention of manned nuclear aircraft from his paper and gave only a description of the Tory Programme, a series of three reactor experiments designed to prove feasibility of ramjet operation on nuclear heat. He noted that the Tory-II series of reactors were designed and operated by the Lawrence Radiation Laboratory, and that the ramjet components had been supplied by the Nuclear System Division of the Marquardt Corporation. Later in the day, Mr. William Weitzen, Deputy Assistant Secretary of the Air Force, announced at the symposium banquet that Chance Vought Aircraft Corporation had been awarded an aero-thermodynamic study of the nuclear ramjet vehicle. Most observers agreed that this award amounted to a contractor selection for design of the vehicle.

Mr. Finger described programmes for two nuclear systems of early importance to space exploration, the nuclear heat-exchanger rocket and nuclear-electric propulsion. Both programmes are in early development stages. Mr. Finger reported that the nuclear rocket could and should be developed first, since it will be most useful for extensive manned operations to the moon and near planets; the later nuclear-electric propulsion system will probably be used for travel to the planets beyond Mars and Venus.

Principal effort in the nuclear rocket programme to date has been devoted to the testing of the three KIWI-A research reactors designed and operated by the Los Alamos Scientific Laboratory. These reactors use uranium-impregnated graphite fuel elements. Fuel plates for the first core were 0·25 in thick with 0·050-in ribs on one side of the plate to provide the gaseous hydrogen flow passage. The second and third KIWI-A reactors used a different fuel element configuration, although all three reactors were outwardly the same. The initial series of three tests revealed certain technical problems and provided confidence to proceed with the next series, the KIWI-B tests, which will include operation with liquid hydrogen rather than gaseous hydrogen as used in the KIWI-A series; also liquid hydrogen, rather than water, will be used to cool the jet nozzle and the pressure shell of the system. It is intended that this next series of tests will lead to a reactor that may be incorporated into the first flight test of a nuclear rocket propulsion system.

The long-term requirements of electric propulsion can be satisfied only through the development of electric systems using nuclear reactor power sources. The first system being developed that will be suitable for early electrical propulsion is the SNAP-8 system. The SNAP programme was recently described in this journal by Anderson and Featherston.[1] It should be noted that the SNAP-8 system used in an upper stage of the Centaur vehicle (first flight of the chemical Centaur is scheduled later this year) could provide a payload capability to Mars equal to the capability of the 1·5 million lb thrust Saturn vehicle.

An overriding consideration in all of these applications of nuclear energy is the requirement that safe operation be assured before the nuclear system may be used.

Flight Reactors

Three sessions of the conference were devoted to Reactors for Flight Propulsion: Physics and Control, Fuels and Materials, Heat Transfer and Fluid Flow. Since more than half the 45 papers given at the symposium were presented by speakers representing contractors in aircraft nuclear propulsion, the reactor sessions and those that followed were characterized by disheartened speakers whose material, though new and previously unreported, was overshadowed by an impending programme cancellation. One speaker translated his description of a current reactor programme entirely to past tense.

The recent operation of HTRE-3 (High Temperature Reactor Experiment), shown in Figs. 1 and 2, gave rise to several papers by representatives of the Aircraft Nuclear Propulsion Department of General Electric. F. Mezger reviewed reactor considerations peculiar to the turbojet application as distinguished from more conventional applications. Propulsion considerations dictate highest possible fuel temperatures, creating materials requirements not unlike other gas-cooled reactors. However, the incentive for maximum heat transfer warrants considerable effort to obtain flat radial power distributions. By varying the hydrogen concentration in the zirconium hydride moderator radially, and by using boron steel strips to flatten azimuthal variations, the highest power in any of 150 fuel cartridges was less than 10% greater than the average fuel cartridge power. An additional consideration results from the thermal inertia of the reactor core, which is obviously much greater than that of conventional turbojet combustion chambers. The induced thermal lag between nuclear power and turbojet power will tend to cause control instability.

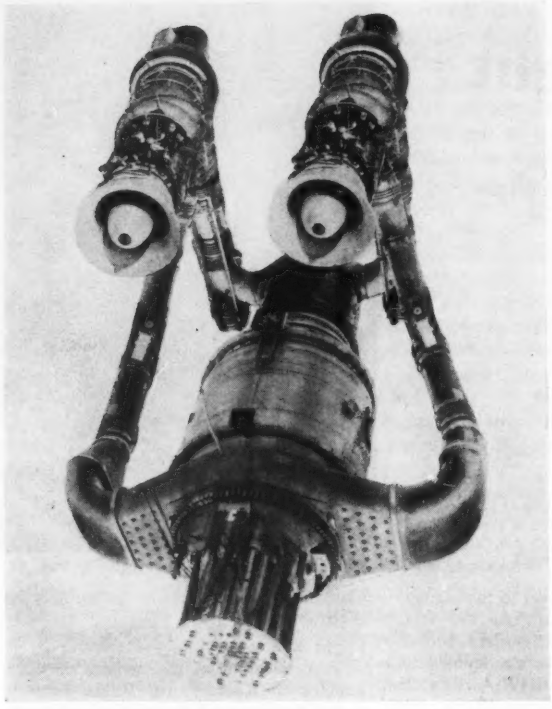


Fig. 2 (Left).—High temperature reactor experiment: reactor coupled to two J-47 turbojets.

Investigation of this instability using analogue techniques was described by T. Elbert, including appropriate control procedures devised prior to HTRE-3 operation. J. Highberg reviewed the previously reported operation of HTRE-3 with two J-47 engines on nuclear heat after chemical start-up and subsequent transfer from chemical to nuclear heat. He then described operation of the system on an all-nuclear start. Temperatures for nuclear and chemical operation are shown in Fig. 3.

Procedures and results for the design of the Tory II A-1 reactor were described by V. Hampel and E. Goldberg. The neutronic calculations performed with one and two dimensional 18-group diffusion codes; an iterative process was described to ensure convergence towards the three-dimensional design point with two-dimensional calculations. Essential parameters are given in Table 1.

B. Dunnington, S. Carniglia, W. Koshuba, W. Hendry, A. Bauer and F. Rough presented papers on fuels of the several reactor types under discussion. Preparation of Nichrome-UO_2 elements was described for air-cooled reactor experiments. Various ceramic fuels

TABLE I—Tory II A-1 Parameters

Average core temperature	1 970°F
Average core diameter	32·1 in
Fueled core length	48·5 in
Overall core length	55·7 in
Fueled core volume	23·6 ft³
Average Oralloy fuel loading in BeO elements	5·95 wt. %
Total mass of OyO_2 (Oralloy contains 93·2% U^{235})	55·9 kg
Moderator to fuel, average molar	222·7
Ratio of flow area to total frontal area of core	0·41

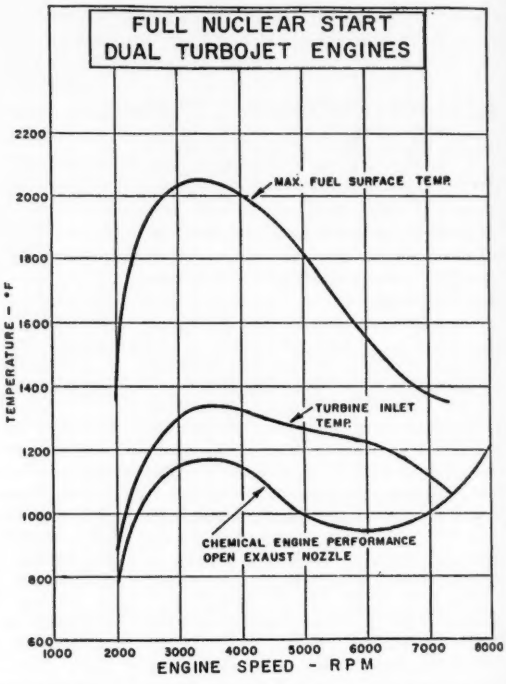


Fig. 3 (Right).—HTRE temperatures for nuclear and chemical operation.

were described, alumina-coated UO_2 and BeO-UO_2, for high temperature air operation, stainless steel clad zirconium hydride-uranium for operation in NaK.

Use of niobium-1% zirconium alloy for reactor structural application and its mill preparation was told by L. Raring. The 100-hour stress rupture strength of this alloy at 2 000°F is about 9 000 psi; in addition, it exhibits outstanding corrosion resistance to alkali metals.

Lithium's superiority as a reactor coolant was discussed in K. Klingensmith's paper by comparison with sodium and sodium-potassium. He announced the use of lithium as coolant in the direct cycle system being investigated by Pratt and Whitney Aircraft.

Advantages cited for lithium are low vapour pressure (2·1 psi at 2 000°F), extremely high specific heat (0·99 Btu/lb°F), and relatively low, short half-life induced activity. Detrimental properties are high melting point (357°F), low density and high viscosity.

Two interesting in-pile loop experiments supporting the indirect cycle powerplant development were discussed in a paper by R. Kelly and G. Parks. These loops, shown in Fig. 4, were fuel element tests in a flowing NaK circuit. Each system was hermetically sealed in a container 6 in square by 9 ft long to fit irradiation space in the ETR. The liquid metal system was encased in type 316 stainless steel. Heat removal control was achieved by varying the airflow rate in an annulus between the NaK container and the reactor process water. Total heat dissipation in the heat exchanger was 826 000 Btu/h, representing rates up to 2 250 000 Btu/ft²h. Total neutron flux for the longest experiment was $1{\cdot}2 \times 10^{21}$ nvt of which 20 per cent. was above 1 MeV.

Ramjets, Rockets, and Auxiliary Power

Project Pluto is a joint Atomic Energy Commission-Air Force programme to determine feasibility of nuclear ramjet propulsion.

I. Hoffman reported that the Pluto project is directed toward reactor operation under difficult conditions: high fuel temperature, high power densities, high flight loads, and high mass flow rates of air coolant. Reactor physics considerations show that this leads to a homogeneous reactor with beryllium oxide moderator. Consequently, early work consisted of research and development on this material. Current work involves the three reactors of the Tory series. The first, Tory II A-1, is a small, low power test reactor. Its purpose is to verify material integrity and aero-thermodynamic behaviour at moderate temperatures. Tory II A-2 is substantially the same, but will be operated near supersonic flight temperatures. The third step involves a full size reactor, Tory II C, operable at power, temperature and airflow rates equivalent to flight conditions.

Two papers on different aspects of nuclear rockets were presented. J. Vreeland and C. Watsen discussed the relationship implied by definition of an optimum fuel element based only on heat transfer considerations and by the limitation to minimum size for criticality. They identify two size ranges of interest by this technique applicable to missions for a Saturn second stage and a Saturn third stage. The latter mission requires addition of reflector mass to achieve criticality with accompanying loss in specific weight. The former, larger, system would appear more efficient and more flexible.

L. Fink and J. Gordon reviewed the non-propulsion nuclear considerations in nuclear rocket design. Most important among these considerations is radiation effects. Sensitivity to radiation of components which must unavoidably be used dictates the shielding requirements in unmanned systems. Use of transistorized electronics is possible if one permits a modest amount of shielding. Radiation effects to seals and structural metals at cryogenic temperatures represent a major item of current interest.

Shielding

The star attraction in most shielding sessions these days is Monte Carlo. W. Edwards and J. MacDonald reflected the trend in describing the integral rôle this technique now plays in aircraft shield design. S. Penny and C. Zerby reported promising results using conditional sampling for deep penetration problems. This technique has the advantage of obviating the need for "guesswork" as does the importance sampling technique.[2]

Running counter to the trend were three speakers, who each reported new analytical work for various applications. J. Moteff described some successes with a simplified method of reactor shield analysis known as the two-component method, which makes use of a collimated and a diffuse component and an approximated surface angular distribution. D. Trubey showed some useful comparisons of gamma-ray air-scattering by a single-scattering approximation with the more complicated Monte Carlo results. T. Johnson, W. Cranford and W. Rainwater reported an evaluation of gradient non-linear programming for aircraft divided shield optimization by comparison with an experiment in which a reactor crew shield system was empirically optimized by an iterative technique.

Radiation Damage

Design approaches to account for radiation-induced damage were described for the nuclear ramjet studies by J. Mitchell and for the NX2 aircraft by J. Levine. The ramjet studies include a radiation "hardening" process which involves several alternatives: replacing radiation sensitive components (i.e., wire-wound resistors in lieu of carbon resistors), derating components (a widely used reliability practice), redesign of system to compensate for effects of radiation. A similar approach has been evolved for the NX2 aircraft with the additional consideration of possible system relocation. Potential system locations are analysed on basis of the flux levels anticipated at the assigned position. Lifetimes are estimated for the system from isodose maps of the aircraft based on exposure rate and the known levels of functional impairment of the materials and components comprising the system. A typical isodose map for the NX2 is shown in Fig 5. The contour lines represent relative isodose levels about the powerplant located in the aft fuselage.

Thus, the additional design alternative may be considered of locating the offending component or system in a position of lower radiation intensity.

Reactor Safety

Papers were heard in the safety session from each of the reactor programmes previously mentioned: G. Graves on rockets; C. DeLorenzo on research reactors; W. Hesse, J. Standefer, and L. Boyer on ramjets; F. Anderson and M. Huntsinger on SNAP systems; I. Russell and J. Werle on aircraft.

Public safety is the foremost consideration in each instance. For each programme it has been shown that the potential contribution to atmospheric contamination is negligible compared with existing levels. Each type of vehicle represents only a limited hazard at the launch or take-off site, which is used to define an exclusion area. In several instances it was shown that chemical hazards for these or existing vehicles require larger exclusion areas than do the radiation hazards.

Although each of these systems (except those for auxiliary power) employ relatively high power levels, fission product inventories are small compared with fixed power stations because of short operating times.

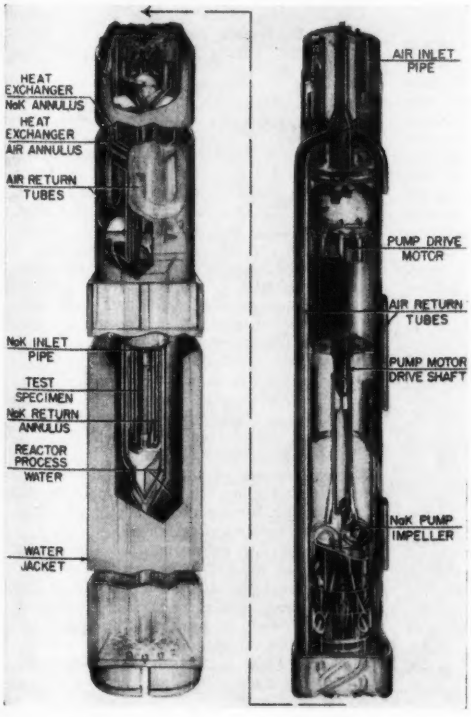
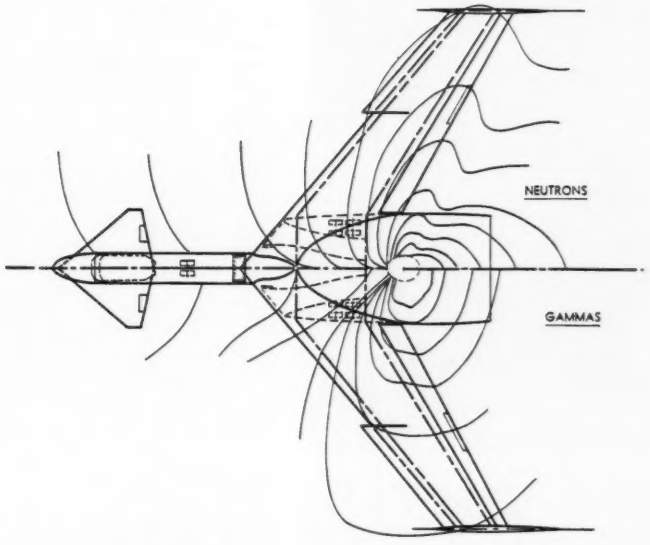


Fig. 4 (Left).—Sodium-potassium cooled fuel element experiment.

Fig. 5 (Below).—Typical isodose patterns for NX2 aircraft.



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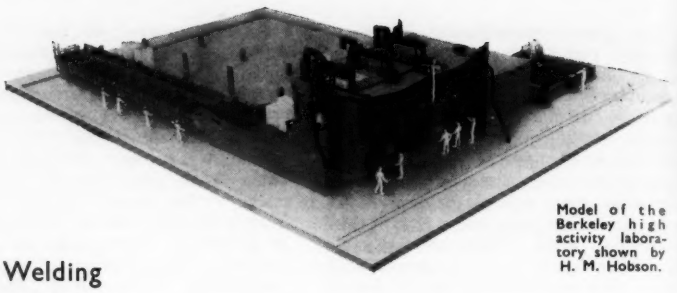
Nuclear Engineering at Olympia, London



Model of the Berkeley high activity laboratory shown by H. M. Hobson.

Engineering, Marine, Welding and Nuclear Energy Exhibition April 20—May 4, 1961

OVER 500 companies have taken space at this year's Engineering, Marine, Welding and Nuclear Energy Exhibition, Olympia, London, and about 35% of them are showing equipment which is either specifically nuclear or at least has been or can be used, with modification where necessary, in nuclear applications. Many of the exhibits have already been publicly seen either at the previous exhibition two years ago or elsewhere, and it is, in fact, disappointing that industry has not made as great use of the opportunity for displaying developments made over the past two years as they surely could have done. For all this, the exhibition is no less interesting and continues to provide a representative selection of the nuclear industry's products.

Few things are more specifically nuclear than an active laboratory and with the CEGB Berkeley Nuclear Laboratories scheduled for formal opening on May 29 it is appropriate to draw attention to **H. M. Hobson's** stand (National, Gallery O 7). They are showing a model of the Berkeley high activity laboratory which they designed and built in conjunction with the CEGB. Alongside the model is a shielded version of the No. 7 Hobson C.R.L. master slave manipulators as used in the laboratory.

The No. 7 manipulators, which are mechanically operated, have 36-in-long master and slave arms capable of a maximum vertical movement of 30 in, backward movement through 28°, and forward movement through 36°. The azimuth movement has a maximum rotation of 355° and the hand grip on the master arms can be twisted a maximum of 400°. Maximum load per arm is 10 lb. The slave arms in the Berkeley version are mounted in lead sockets let into the cell roof so as to reduce radiation from the aperture through which the manipulator operates. Further protection is afforded by the provision of plastic coverings over the wrist assembly and arms of the slaves without impairing their flexibility. Hobson also show a control gear box for heavy-water reactors as shown previously.

Prototype 8 ft 6 in CO_2 gas duct cascade bend for Trawsfynydd, designed to accommodate 5 ft 6 in ducting and working pressure of 250 psi, about to undergo tests at the Wallsend works of Richardsons, Westgarth and Co. A model is shown on their stand.

In the displays of equipment specially designed for the nuclear power stations now under construction and not previously shown emphasis is on Trawsfynydd. **Richardsons, Westgarth and Co.** (Grand G 7) show the bellows restraint mechanisms for this station which is of a new design and was described in *Nuclear Engineering*, October, 1960. They also show a CO_2 blower rotor and a scale model of the cascade corner bend for the CO_2 circuit. During the exhibition a film on site progress is being screened.

Cascade Corner Bend

In most aerodynamic circuits the cascade bend is stressed on the assumption that the vanes stiffen the elliptic section of the bend and the welds between the vans and skid plates perform satisfactorily. In a nuclear CO_2 gas circuit, however, difficulties arise because only fully X-rayable welds are acceptable as load bearing joints; further, the reinforcing action of the vanes upon the casing has to be disregarded. The cascade corner bend developed by Richardsons, Westgarth consists of a sphere, which carries the pressure load, and inside it is a light, pressure compensated structure for deflecting the gas. The sphere, of 8 ft 6 in dia. accommodating a 5 ft 6 in dia. duct, is stressed in pure tension and its wall thickness satisfies the requirements of B.S. 1500. The circular openings are provided with 100% compensating rings and because they are plain, machined butt welding and automatic welding are possible. It is expected that working pressures up to 300 psi at 410°C could be taken by the shell if neccessary. Any angle of bend is possible.

Attention is again drawn to the Trawsfynydd gas circuit by **Aiton and Co.** (National M 7) who are showing some of the 18 in dia. corrugated piping for it. Piping for a different purpose, for the Trawsfynydd steam raisers, in fact, is displayed by **Tubes** (Grand A 12). This is of the seamless type and is internally ribbed. Tubing for the H.P. superheating is 2 in dia. and has 38 ribs while that for the L.P. is 2 in dia. and has 40 ribs. Both types are provided with resistance welded fins.

A model of Sizewell, site work on which started at the beginning of April, is to be found on the **Babcock and Wilcox** stand (Grand G 4). They are also displaying a model of the marine propulsion saturated water reactor, the design for which was one of the five submitted to the Ministry of Transport early last year.

English Electric, who are building Sizewell with Babcock and Wilcox and Taylor Woodrow Construction, show on their actuator stand (National S 2) a rotary actuator for valve control at this station. Torque outputs from 80 to 8 000 lb/ft are provided and the rotary motion is given by a 400–440 V 3 phase 50 cycle squirrel cage induction motor.

Much of the equipment destined for the older stations is familiar. **Fluidrive Engineering** (Grand H 4), for instance, are again showing a Vulcan Sinclair double circuit fluid coupling unit similar to the 16 supplied to Berkeley and **AEI** (Grand N 6) are showing photographs of the 83 MW turbine generators installed there. **John Thompson** (Grand F 3) have a model display of their steam raising equipment and **Cape Asbestos** (Empire BB 2) refer to their insulation work. Insulation on other projects is highlighted by the **Darlington Insulation Co.** (National L 4) and **Turner Asbestos Cement Co.** (Empire AA 10).

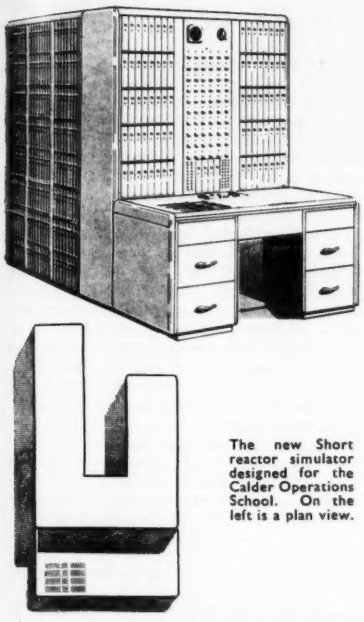
Reinforcement Rings

The main display by **Darlington Forge** (Grand H 15) is a 5 ton gas duct reinforcement ring similar in design to those supplied to Bradwell. In conjunction with Whessoe, this company has developed new forging techniques for fabricating rings of this sort and as well as supplying rings for gas ducts have produced reinforcing rings for use on the Dungeness and AGR heat exchangers and cambered rings for reinforcing openings in the AGR reactor pressure vessel. A rotary gas sampling valve for Bradwell's B.S.D. circuit is shown by **C.A.V.** (Grand A 8). Electrically operated it has 18 positions and is designed for long continuous operation without maintenance.

Munro and Miller (National, Gallery I 2) display samples of their bellows expansion units. Particular attention is paid to the bellows unit for the charge/discharge equipment at Hunterston.

While it not surprising that few of the commercial exhibits relate to the AGR at Windscale—companies on the whole, British ones at least, prefer publicizing their contributions when a project is complete and in operation—it is a slight disappointment that the AEA could not have filled this gap by taking a stand just to show what is going on there.

One of the few references to the AGR



The new Short reactor simulator designed for the Calder Operations School. On the left is a plan view.

is made by **Short Brothers and Harland** (National, Gallery O 11) who are displaying a quarter-size model of the new Short Reactor Simulator. Designed for use at the Calder Operations School, it is made to simulate the Magnox reactor operation, but with slight modification can also be used for AGR simulation. It is a large special systems analogue computer with 200 computing amplifiers and will simulate a wide range of fault conditions as well as normal operations.

A less elaborate simulator is demonstrated by **NETAC** on the **British Engineers' Association** stand (Grand, Centre) where, in addition, four films are being screened. One of these—" Reactor Systems "—is comparatively recent.

Allusion to the AGR is also made on the **ICI** and **Marston Excelsior** stand (Grand, Gallery O 30) where samples of wrought beryllium as well as of zirconium, hafnium and niobium can be seen. Neutron shielding provided by the " Boroplast " technique is also shown. Boronated plastic in the form of chips or granules containing 1–10% boron are immersed in a matrix having a high hydrogen content, e.g., water, oil or a suitable resin such as a polyester, silicon fluids, or polyurethane. " Boroplast " is being manufactured to various specifications under licence to ICI and some 60 tons have been made for shielding on the Berkeley charge-discharge machinery.

Flash welded tubes and components are shown by **Reynolds Tube Co.** (National, Gallery I 22), who feature samples in heat resisting and stainless steels, nimonics and titanium alloys. **The Anti-Attrition Metal Co.** (Grand, Gallery O 7) and the **Birmingham Battery and Metal Co.** (Grand 3 A and National P 8) show samples of their aluminium, aluminium manganese, and bronze castings. The last-named company also exhibit models of heat exchange condensers and salt water supply pipes fabricated from " Battery " bimetals similar to those supplied for nuclear plant. Steel forgings for generation plant are shown by **Firth Brown** (National Q 7).

Steel Extrusions

More steel fabrications, this time of the extruded variety, are shown by **Alexander Marcar and Co.** (National, Gallery I 18), agents for Schwerter Profileiserwalzwerk Aktiengesellschaft. Recent developments have made it possible to raise the maximum cross section for production extrusions to 6-7 in so enabling the range of products to be extended. All varieties of sections, both solid and hollow, can be extruded in lengths of up to 82 ft and in weights of up to 20 lb/ft.

Stewarts and Lloyds show steel tubings including specimens of the double concentric Winfrith effluent piping and the **Extended Surface Tube Company,** the joint ICI-S and L company, on the same stand display samples of Integron steel and stainless steel finned tubes. Also exhibited are samples of Stewarts and Lloyds non-ferrous and plastic tubes. The highlight, however, is the resonance fatigue testing machine.

This has been specially designed for use on finned tubes, to test the soundness of the tube and the welding of the fins. A tube is supported at opposite ends and by means of two contra-rotating weights attached to each end vibrations are set up. The amplitude of these increases as the frequencies of the weights approach the natural frequency of the tube. In a fatigue test the tube is vibrated at a fixed amplitude, established by the speed of the d.c. motors that drive the weights, until the occurrence of a fracture, detected by a pressure drop in the tube.

Test equipment is also prominent on the stand of that other well known tube manufacturer, **Accles and Pollock** (Grand, Gallery I 47). Ultrasonic detection of a mid-wall flaw in a 1¼ in dia. tube with ¼ in thick wall is demonstrated. Eddy flow detection equipment, used for testing smaller bore, thinner walled tubes, is also featured. Fuel element cans, heat exchange tubes and the world's reputedly smallest seamless tube (o.d. 0·00073 in ; bore 0·0001 in) are on the stand.

Ultrasonic testing is also featured by **Metal and Pipeline Endurance** (Grand, Gallery I 8) who in addition demonstrate stress relieving of pipeline, gamma radiography for weld inspection, and ultrasonic thickness measurement.

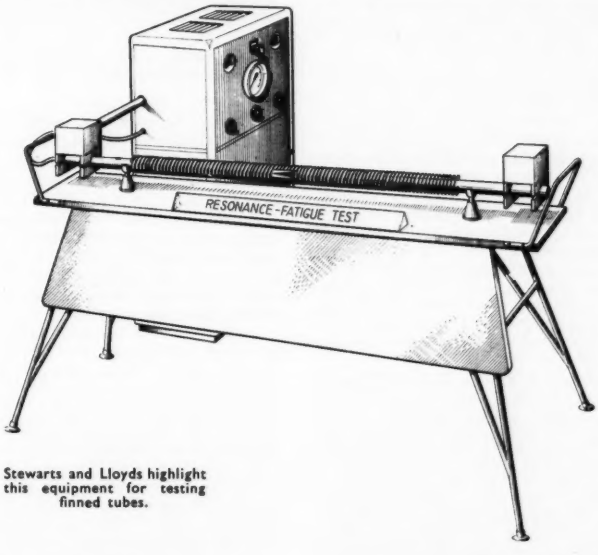
A 28 lb flaw detector with a 5 in fine definition high brightness display is shown by **Ultrasonoscope** (National, Gallery O 4). It is capable of thickness measurement without the use of ancillary equipment. When used for routine inspection an exceptionally clean trace can be obtained by means of a control which allows small defect echoes to be contrasted with spurious grain boundary echoes. Another new instrument is the automatic, high speed immersion testing tank for round bars and tubes.

Ultrasonic flaw detection equipment is also demonstrated by **Smiths Industrial Division** (Empire Z 3) where the Mark 6 model is on view. It operates with barium titanate probes having single, twin or separate transmitter and receiver heads and is suitable for contact, gap or immersion scanning techniques.

Compact Creep Testing

Testing equipment of a different nature is shown by **Mohr and Federhaff AG** (Grand A 14)—the Siemens designed creep machine in which 12 specimens can be creep tested at once and without the need for any special air conditioning—this is contained within the machine. Further, the machine is so designed to enable simultaneous tests at three different loadings to be carried out. Loadings possible range from 550–4 400 lb. An automatic device removes the loading if a specimen becomes unintentionally cool.

Equipment for testing tensile, bending and compression strengths and elasticity is also shown, together with a furnace for conducting tests at elevated temperatures.



Stewarts and Lloyds highlight this equipment for testing finned tubes.

Similar equipment is displayed by **W. and T. Avery** (Grand E 3).

Also from the Continent are **Simmering-Graz-Pauker**, of Vienna (Grand K 14), who are showing photographs of the equipment they have supplied for the 12 MW Siebersdorf reactor, a model of which is being shown by **AMF** (National Q 8) who are at the exhibition for the first time. Their principal exhibits are the **Pye** master slave manipulators.

Reactor components are shown by **Talbot Stead Tube Co.** (Grand, Gallery I 34). They include breeder thermocouple guide tubes for Dounreay, fuel element supports and a charge plug. Models of a control rod fabricated from stainless steel with boron inserts, a mild steel restraint tie bar and a mild steel charging standpipe assembly are also displayed.

The blower of a test rig for a gas cooled

reactor is featured by **Plannair** (Grand, Gallery I 21). It has a 11 500 rpm motor and is designed to work within a pressure range from atmospheric to 300 psi and at temperatures up to 350°C. Mass flow covers a range from up to 8 000 lb/h. Plannair also show axial flow blowers of the type supplied for use in *Dreadnought*.

Fans for nuclear submarines are also shown by **Keith Blackman** (Grand A 1) who have supplied several American vessels with slotted blade axial fans. The slots are reputed to give boundary layer control and extend the laminar flow over a large part of the blade chord, resulting in high efficiency at lower speeds, with a corresponding reduction in turbulance and blade friction, noise size and weight.

More fans and ventilation equipment are to be found on the **Air Control Installations** stand (Grand, Gallery O 29). Highlighted is the " Velovent " system of air conditioning which is compact and easy to install.

Filters are featured by **Vokes** (Grand E 4). A model demonstrates the versatility and compactness of their " Unipak " system of housing banks of filters. Any combination is possible and each filter can be easily removed and replaced without disturbing the others. " Unipaks " are to be found in many nuclear installations. On another stand **Dallow Lambert and Co.** (Empire BB 3) display some of their duct control equipment which likewise has nuclear applications. One installation to which attention is drawn is a graphite plant equipped with type 2/6000 " Drytube " dust filter and cyclones capable of handling 30 500 cfm of dust laden air.

Filters for liquids are to be found on the **Auto-Klean Strainers** stand (Grand D 3). The latest addition to their range is the Auto-Klean Koten, which has been used in plant for submerged machining of radioactive components in demineralized water. The requirement was for a non-collapsible filter with expandable elements capable of coping with 450 gal/h of water at high pressure differentials. The filter supplied has four elements each fibre-wound to provide a 10 micron grade filter.

Filter regulators are shown by **C. A. Norgren** (Grand, Gallery O 40). New is the 73AC unit available in ¼ in and ½ in pipe sizes.

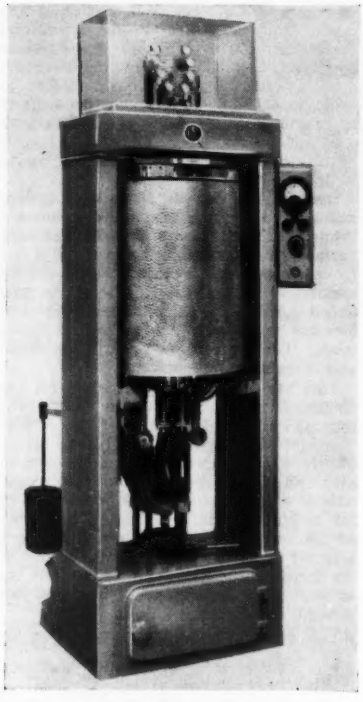
Fluid sealing devices shown by **Pioneer Oilsealing and Moulding Co.** (Grand, Gallery 16) include two additions to their range. First of these is a labyrinth seal developed to replace the conventional metal labyrinth seal on conveyor idlers and the other a simple carbon face seal. Rotary oil shaft seals are shown by **George Angus and Co.** (Empire AA 3) and oil seals with rubber wiping lids are featured by **Charles Weston and Co.** (Grand, Gallery O 33).

Beldam Asbestos Co. (Grand D 3) show rotary shaft packing and recommend that their Beldemok, a plaited asbestos, can be used under temperature and pressure conditions of 650°F and 1 000 psi. Another product highlighted is Lascarflan; which is designed for corrosion resistant duty.

Rotary exhausters as supplied to Berkeley, Harwell and Winfrith are shown by **The B. A. Holland Engineering Co.** (Grand B 5). They are of the vane type and range in power up to 300 h.p. Two-stage machines are also available.

Valve Range

Newman, Hender and Co. (Grand H 9) are making under licence from Canada the range of Newman Velon valves, forged steel bonnetless gate and globe type. In the gate type, designed for working pressures up to 600 psi at 800°F a service cover and test plug in the base enable the valve to be tested under pressure with, for instance, a compressed air source. The globe type is primarily intended for high temperature service and can be supplied as stop, stop check or needle valve. Both types are available in a size range up to 2 in. These valves are also being shown by **British Steam Specialties** (Grand G 3).



The Siemens designed compact creep testing machine shown by Mohr and Federhaff.

A 16 in cast carbon steel valve is featured by **Crane** (Grand G 10) and illustrations show a similar valve installed in a plant where temperatures and pressures of 1 030°F and 535 psi are experienced.

PVC and Ptfe valves are shown by the **Saunders Valve Co.** (National R 5). The PVC units are available in sizes ranging from ½ in to 2 in and are intended primarily for solvent welding to PVC piping. The Ptfe valves are as yet only available in the ¼ in and ½ in sizes.

Equally small is the new isolation valve developed by **Teddington Aircraft Controls** (National, Gallery O 13) for nuclear applications. Bore sizes are up to ½ in and a maximum design leakage across the seat in the closed position is 0·001 lb/hr at 600 psi.

Hydraulic equipment as supplied to the AEA at Dounreay, Aldermaston and Harwell can be seen on Stand A 16 Grand Hall, where **Keelavite Hydraulics** feature an hydraulic gear/pump motor which as a pump has a capacity of 96 cu in/rev and as a motor a torque of 1 400 lb/in/100 psi is developed. Also shown are Keelavite pipe couplings which are normally made in cadmium steel but are now also available in stainless steel.

Bristol Siddeley (National, P 6) show the ball screw—an application of the bearing technique to the screw thread. The possible applications for this simple, effective device are numerous; one of the largest units made by Bristol has been a 30 ft long screw for use at Hinkley Point.

A motor of interest to those who want to produce intermittent motion is the Twiflex Hilliard intermittent drive unit on the **Twiflex Couplings** stand (Grand, Gallery O 2). The single revolution clutch is a well-known device for producing intermittent motion from a steady rotary source. This unit provides the same effect by means of a compact, ready-to-fit packaged assembly without the need for additional components.

Also being shown for the first time is **Tangyes** model H " Hydraflo " high-pressure pump (Grand J 5). A double-acting reciprocating unit, it covers output pressures of up to 9 000 psi, output quantities of up to 75 gal/h and input powers of up to 90 h.p. Output flexibility is achieved by providing a selection of oil-driving and water-pumping cylinder sizes and a variable-speed transmission drive.

New from **Worthington-Simpson** (National S 4) is a sump pump. Designed to run at 7 900 r.p.m., it can be powered by 1½ h.p. to 10 h.p. motors and can cope with up to 300 g.p.m. of acids, alkalis and slurries.

Valves, jacks, hydraulic motors and self-sealing couplings are shown by **Lockheed Precision Products** (Grand D 4). Featured is a titanium stabilized stainless-steel bayonet-operated self-sealing coupling as supplied to the AEA.

Valves are also to be seen on the **British Area Regulators** stand (Grand A 6) who are also showing some new instruments including a temperature transmitter and an electro-pneumatic positioner. The transmitter is of the bi-metal type and has a temperature range of −100°F to +1 250°F.

An unexpected but interesting exhibit, unexpected because it would seem to belong more to a civil engineering exhibition, is the sectional hoist tower shown by **Sterling-Safway (Sterling Foundry Specialties)** (Grand B 4). Said to be the first of its kind produced in Britain, each section comprises a welded frame 6 ft 4 in high by 6 ft 6 in deep and 5 ft 6 in, 7 ft or 8 ft 10 in wide. Any conventional cantilever or centre slung goods hoist as well as the majority of passenger hoists can be accommodated.

Canadian Exhibits

Instruments form the backbone of the **Nuclear Enterprises** display on the **Canadian Government** stand (Grand K 16). This company is associated with the Edinburgh company of the same name and prominent among its exhibits is the Berylometer, a scintillation counter which makes use of the Be^9 (γn) Be^8 reaction and is used for detecting the presence of beryllium in mineral deposits. It has a 5-in. photomultiplier tube and boron polyester zinc sulphide disc. It is fully transistorized and has only two controls. The radiation source is antimony.

Thirteen other companies are exhibiting on this stand, including **Atomic Energy of Canada,** who are concentrating on their cobalt-60 irradiation unit—the Gammacell 220 (described in *Nuclear Engineering*, January, 1960), and **Electronic Associates,** who have a model railway on show! Its purpose is not principally to provide tired visitors with a little relaxation but to demonstrate the use of radioisotopes for identifying and keeping track of trains. The last truck of each train is equipped with a gamma source, each source being devised to provide its own individual configuration of rays. When the source passes over detection equipment sited at selected points on

Welding Exhibition Highlights

the track the traffic controller at a central point is automatically informed of the train's position and identification.

Although prominence is given to automatic welding by **Murex Welding Processes** (Empire W 2) manual welding with new and improved electrodes such as those used on the *Dreadnought*, the AGR and at Dounreay is not overlooked. The hull of the *Dreadnought* was welded entirely by hand using electrodes in the Fortrex series. Over 1 million of these specially developed rods were required. A complete series of Fortrex 35 electrodes has been introduced for mild and carbon steels in the 30-35 ton range whilst a second group of Fortrex electrodes covers the high-tensile steel range.

The new Muramatic automatic welding equipment on display has been designed for use either with submerged arc or open arc process using a.c. or d.c. supply. Another exhibit is the new model of the 300/400 amp " Overlander " mobile diesel engine set specially designed for site work.

Low temperature welding of alloys is highlighted by **Weldcraft** (Empire 22) who have introduced a completely new range of low heat metal joining alloys called " Obvis." A bond is achieved by the building up of a surface alloy between the parent metal and the deposited metal. There is no fusion of the base metal and little heat transference to the surrounding metal takes place.

The welding of end fittings to preformed tubes can be tricky, particularly if high temperature and pressure conditions are present and great accuracy is required. **Palmer Aero Products** (Grand A/11) maintain that the problems can be overcome with the Precision Orbital Welding Technique. This effects a butt weld between a fully formed tube held in a fixed position and an end fitting positioned in the correct relationship to it. Weld crown and penetration dimensions can be so finely controlled that as much as 95% of the tube diameter is maintained.

Newest addition to the range of **Vacu-Blast** (Empire W 6) shot blasting equipment is the Majorette which uses a ¼ in supersonic nozzle and gives an output nearly double that of the Medium unit and a little over a half of the Major. It is demonstrated in conjunction with the Crawler which is used for scale and rust removal from flat plate. Of particular interest to the welder is the Minor, designed for slag removal in small areas.

Co_2 Welding

Featured by **Arc Manufacturing Co.** (Empire V 5) is the semi-automatic carbon-dioxide welding process equipment incorporating A. O. Smith C-O Manual components for which Arc are sole concessionnaires in the U.K. The unit consists of a lightweight hand gun, integrated wire drive, control unit and a 600 amp constant potential power source. Slope control is provided, giving five position adjustments of output ranging from flat (0·6 V/100 amp) to drooping (8 V/100 amp). The rectifier has a voltage range of 115-45·5 V at rated load. A built-in 2 kVA 115-230 V control transformer is provided for powering accessories and there is a fixed 180 amp outlet for tack welding. Another exhibit is of the redesigned three-phase rectifier and they are also showing a redesigned polytrode which has a spark ionizer for facilitating arc-welding by the superimposition of a high frequency current on the normal low voltage welding current.

Carbon dioxide welding is also featured by **Lincoln Electric Company** (Empire U 4) who are showing the newly developed SPRITE equipment. It consists of the new Lincoln CV 400 motor generator (a constant voltage type providing 400 amps continuously at 40 arc volts) the Lincoln SPRITE welding unit (incorporating variable drive, wire reel with adjustable spring loaded mechanism to take up slack in wire, remote amperes button, ground clamp) and the Lincoln FW 1 CO_2 welding gun.

The main feature on **Crompton Parkinson's** stand (Empire W 4) is the demonstration of argon shrouded stud welding of light alloys. The process has the effect of minimizing porosity and atmospheric contamination by introducing argon gas through a brass shroud into the weld zone and remaining there. A valve attachment at the base eliminates gas wastage by releasing the argon flow only when the handtool is in position. Also shown for the first time is a new type transformer rectifier which has a maximum output of 4 700 amp and enables ¾ in studs or shear connectors to be welded at high duty cycles. It is a vertically mounted forced air cooled unit, with infinitely variable current adjustment over the range for which it is designed to operate.

On loan from Harwell on the **F. Hirschman** stand (Empire W 9) is a machine for automatic argon arc welding of aluminium fuel cans. As soon as an arc is struck, the tube is rotated for a set time. The rotation speed is then increased to prevent the formation of a weld crater, after which the machine is switched off. Current, rotation speeds and the position of the electrode head are adjustable. An automatic gas flow control is fitted to stop the process if the gas supply fails. After the completion of the first weld the can is evacuated through a small opening at the swaged end, which is then sealed by hand using a small argon arc unit.

Automatic argon arc welding unit supplied by F. Hirschman to AERE, Harwell, for welding fuel cans. It is used in conjunction with a small hand welding machine for sealing the swaged ends.

Cutomation is the name given to **British Oxygen's** (Empire W 5) new oxygen fed high speed profiling head. Speeds are said to be increased by 50% using this method compared to previous methods. Also new is the Harris designed Model 42 universal pressure multi-purpose torch. It can weld, cut, heat, flame clean, gouge and rivet wash. It works on low pressure gas down to 6 oz /in².

High speed cutting can also be seen on the **Suffolk Iron Foundry (1920)** stand (Empire Y 3). The new S.I.F. 75 Cutamatic precision oxy-flame cutter is designed for repetition cutting from metal templates, tracings or to individual shapes, guided by a special control wheel. Two cutting heads with independent space adjustment are normally provided and they can be used with acetylene or propane gas. Other features are the retractable cutting table and an electromagnetic template feeler which enables accurate precision cuts on a mass production scale to be made.

Suitable for areas where trained maintenance engineers are few is the LWAD range of welding equipment made by **English Electric** (Empire W 4). These units can give a.c. or d.c. outputs and are oil cooled, including the silicone diodes, and so cannot be damaged by overheating.

Miller welding equipment is being shown by **Interlas,** of Ampthill, Bedford (Empire V 9). Featured is the Sigma welder with controlled slope and available in three sizes with 100% duty cycle welding current ratings of 300, 500 and 1 000 amp. The welder automatically provides the correct current to burn off the filler wire at the rate necessary to maintain a constant arc voltage. If the wire feeding speed should momentarily increase, or other conditions cause the arc length to shorten, the welding current of the welder automatically increases. This burns off the excess filler wire rapidly enough to maintain a constant arc length and/or voltage until the feeding speed returns to normal.

Submerged arc welding is featured by **AEI Transformer Division** (Empire V 5). The equipment displayed is for high-speed deposition of weld metal to high radiographic standards using a bare electrode and granular flux. Electronic control ensures a reliable arc and instantaneous initiation of the arc to overcome imperfections at the beginning of the weld. It can operate on either a.c. or d.c. and can be readily converted for open arc welding. Modified heads can be supplied for Co_2 welding.

New Bi-Metal Thermometer

A bi-metal high temperature thermometer that is one-third cheaper than a mercury-in-steel instrument with the same range is highlighted by **British Rototherm Co.** (Grand, Gallery 113). It has a range of 200°F to 1 200°F and will withstand oxidation up to 1 400°F. It comprises a self compensating and shock resisting multiple helix carried in a stainless steel stem. Dial sizes are 2½ in, 4 in and 7 in giving a scale length of 5 in, 7½ in and 14 in. Vertical or horizontal mounting is available. Also new are a three-stage mercury in steel temperature controller available in any range within the limits of −30°F and to +1 200°F, and a temperature controller which will control between fixed differentials and record the temperatures on a chart.

Welding Equipment Survey

The tables on this and the following page present a guide to British manufacturers of welding machines, power and gas supplies and ancillary equipment. The information given is a digest of that received in response to an invitation by *Nuclear Engineering* to manufacturers to outline the services they could provide.

ANALYSIS OF DIFFERENT WELDING SYSTEMS

COMPANY	Gas	Metal Arc								Fuel elements	Electro-slag	Electron beam	RF	Resistance						
			Argon/He	CO_2	CO_2 vertical plate	Submerged	Fine wire	Atomic H	Twin fillet					Stud	Butt	Flash butt	Stitch	Seam	Spot	Projection
AEI Transformer Division		×	×	×		×		×		Zr				×		×	×		×	×	×
Al Electric Welding Machines														×					×	×	×
Arc Manufacturing Co.			×	×																	
ARO Machinery Co.														×					×		
F. Bode and Son																		×			
British Federal Welder and Machine Co.			×	×		×								×							
British Industrial Gases	×																				
British Oxygen Co.	×	×	×			×	×														
Courtburn Positioners															Ag	Ag			Ag		
Crompton Parkinson														×							
Edwards High Vacuum												×									
English Electric Co.		×																			
General Electric Co.		×																			
F. Hirschman		×	Ag	Ag						×											
Hirst Electronic		×	×	×																	
H. M. Hobson										Be											
Holden and Hunt															×	×			×	×	
Interlas		×	×	×										×							
Kerry's (Ultrasonics)																					
Lincoln Electric Co.		×		×		×															
Meritus (Barnet)														×	×			×	×	×	
Messer Industrial Engineering	×	×	×	×										×	×			×	×	×	
Murex Welding Processes		×				×			×												
Oerlikon Electrodes (Gt. Britain)			Ag	Ag																	
Petbow		×																			
Portable Welders		×																	×		
Redifon													×								
Research and Control Instruments				×																	
Rockweld		×		×	×	×					×							×			
Rowen-Arc			×	×																	
Saturn Industrial Gases	×		×																		
Sciaky Electric Welding Machines														×		×	×	×	×	×	×
Siemens Schuckert (Gt. Britain)										Mg				×				×	×	×	
Spembly							×									×			×		
Suffolk Iron Foundry (1920)	×																				
A. S. Young and Co.	×	Ag	Ag											Ag							

ELECTRODES AND WIRES

AEI, Transformer Division — Mild steel inc. Sylvick; Speedivick 1, 2; Gazelle; Tensivick, 35; 35V, N. Stainless steel inc. Pyrovick 25/15. Creep resisting inc. Lo-creep MoV. High tensile inc. Tensivick 45; Nichrovick BP. Hard surfacing. Cast iron.

Arc Manufacturing Co. — Mild steel (8 types). Chrome moly (6) Stainless steel (6). Low alloy, Low H_2 (3). Hard surfacing and Mn (5). Aluminium (4). C.I. (3). Bronze (3).

ARO Machinery Co. — Copper/chromium alloy.

British Oxygen Co. — Over 50 types of arc welding electrodes inc. Ferron No. 3. Wires for argon and CO_2 shielded welding of m.s., s.s. and Al.

Deloro Stellite — Hardfacing rods, electrodes and powders.

English Electric — General purpose, in comprehensive range, inc. electrodes for c.s., s.s., Mn and alloy steels.

Hirst Electronic — Spot welding electrodes.

Holden and Hunt — Scadcu alloy for spot welding electrodes and flash welding dies.

Interlas — Pure tungsten, 2% thoriated tungsten.

Lerche Machine Tools — O.K. electrodes.

Lincoln Electric — Mild steel inc. Multiweld, O.V.; Jetweld 1, 2; Fleetweld improved 5, 7; Nu5, 7, 1. Medium, high tensile steels, Shield-arc 85; Nuweld 2. Austenitic and heat resisting steels, Stainweld A-D; Austenweld A, C. High tensile and chrome bearing, Chromeweld 1, 2, 4–6, 9, 12. C.I. Bronze. Cu. Hard-surfacing.

Meritus (Barnet) — Electrodes for spot, seam, butt and projection welding.

Messer Industrial Engineering — Electrodes for arc welding of m.s., s.s., heat resisting; Elin Hafergut process; rods for shielded arc.

Murex Welding Processes — Iron and mild steel inc. Coilex, F; Cuprex; Deepex; Fastex 5, 7, 100; Fortrex 30, 35, 35A; Genex; Ironex 2, 5, 7; Molex; T.P.W.; Vodex. High tensile steels, Armex 2, 3; Fortrex, 45, 55. Creep resisting, Suprex A, B, C, M. Hardfacing, Hardex 250, 350, 450, 650, 800, CHR, T; Tubex; Manganese P, Nickel. Stainless and heat resisting. Armex GT; Chromex 1, 2, 3; Nicrex, F, NDL, NDR, MCL, MR, MC55, HR, P, I, ICb, 2, 3, 4. Non-ferrous, C.I.

Oerlikon Electrodes (Gt. Britain) — Mild steel inc. Fincord; Citobest; Supercord; Overcord; Rapid; Pyrocito deep penetration; Special, Supercito low hydrogen. Stainless steel, Silvercord 18/8/Nb, 18/8/3, 25/20; Ferinox. Hardfacing 250, 350, 600; Super-chrome; Manganese; Toolcord. Creep resisting, Molycord 5; Chromoly 15, 21, 55. Cutting. Non-ferrous.

Portable Welders — Spot welding electrode tips. Low voltage arc electrodes.

Redifon — Brass contour for RF welding.

Research and Control Instruments — Wires for CO_2 shielded welding.

Rockweld — Arc welding electrodes for m.s., low alloy, high tensile steels, hard surfacing, stainless, heat resisting steels. C.I. Non-ferrous. Comet flux cored wire for CO_2 process. Detron fluxes for submerged arc and hard surfacing.

Rowen-Arc — Wire for m.s., s.s., aluminium alloys.

Saturn Industrial Gases — Agents for all types.

Sciaky Electrical Welding Machines — Blue, Red and White, spot standard electrodes. Specials.

Spembly — Portable tools with graphite, tungsten and copper chrome electrodes.

Suffolk Iron Foundry (1920) — Oxy-acetylene electrodes.

A. S. Young and Co. — Agents for argon-arc tungsten; bare wires for gas and argon arc; coated electrodes for arc. Spot welding tips.

CUTTING EQUIPMENT

British Industrial Gases	Gas equipment.
British Oxygen Co.	Saffire gas equipment; oxy-acetylene, oxy-propane.
Centrajet	Oxygen equipment.
English Electric Co.	Electrodes.
Hancock and Co. (Engineers)	All types of oxy-cutting, profiling and flame planing machines.
Messer Industrial Engineering	Gas cutting and surface hardening; electronic control.
Pollock and Peel	Gas equipment.
Rowen-Arc	Rowen-Gloor automatic flame cutting.

SUPPLIES

AEI, Transformer Division	Generators, transformers, rectifiers, sets.
Arc Manufacturing Co.	Air, oil cooled transformers; single, multi-operator, rectifiers, dual output.
British Oxygen Co.	"Quasi-Arc" a.c. transformer sets; d.c. rectifiers; generators, motor and mobile engine for manual welding; power sources for Argonarc, Fusarc, Fusarc/CO_2, Unionmelt, Sigma processes. Oxygen, acetylene, propane, inert and shielding gases.
English Electric Co.	Multi-operator transformer units, portable regulators, a.c./d.c. portable, automatic units; silicon rectifier units.
General Electric Co.	Single and multi-operator welding supplies up to 60 kVA.
F. Hirschman	Transformers and rectifiers.
Hirst Electronic	A.c. reactor.
Interlas	Agents for Miller a.c., d.c., a.c./d.c. equipment.
Lancashire Dynamo and Crypto	Generator and motor generator sets up to 1 000 A.
Lerche Machine Tools	Agents for air cooled arc welding transformers.
Lincoln Electric	D.c. motor generators, and engine driven; d.c. rectifier, and a.c. transformers.
Messer Industrial Engineering	Transformers; converters, diesel and petrol; rectifiers. Gas generators.
Murex Welding Processes	Single, multi-operator transformers; rectifiers; generators; motor generators and engine-driven.
Oerlikon Electric (Gt. Britain)	Agents for manual welding transformers.
Petbow	Diesel engine, electric motor sets.
Portable Welders	Portable toroidal arc, 300 A.
Redifon	Radiofrequency generators.
A. Reyrolle and Co.	D.c. arc welding generators with (or without) a.c. induction motor or petrol engine drive.
Saturn Industrial Gases	Argon-arc a.c. surge injector; d.c. units. Gases.
Sciaky Electric Welding Machines	Three phase balanced load resistance welding plant.
Spembly	Capacitor discharge.

HEATING

AEI, Transformer Division	Resistance heaters.
British Industrial Gases	Gas heating.
British Oxygen Co.	Gas preheating equipment.
Electrothermal Engineering	Portable, flexible heaters for preheating, stress relieving, heat treatment. Armoured types. Flexible furnace.
Messer Industrial Engineering	Preheating torches. Electric preheat.

ANCILLARIES

British Federal Welder and Machine Co.	Electronic control units.
British Oxygen Co.	Torches, electrode holders, protective clothing, tools, instruments, etc.
Courtburn Positioners	Agents for holders, magnetic clamps, vices, etc.
Edwards High Vacuum	Equipment associated with electron beam welding.
Hirst Electronic	Magnetic amplifier controls, current meters.
Interlas	Torches, holders.
Messer Industrial Engineering	Wide range.
Murex Welding Processes	All types.
Pollock and Peel	Cutting and welding nozzles. Torches.
Rowen-Arc	Protective clothing, regulators, clamps, cables, etc.
Saturn Industrial Gases	Argon-arc torches. Gas and arc welding accessories.
Sciaky Electric Welding Machines	Electrode holders and adapters.
A. S. Young and Co.	Argon-arc accessories. Pressure measurement for spot welders.

JIGS AND MANIPULATORS

F. Bode and Son	Rotators, columns and booms, travelling gantry, conventional welding positioners, strip clamping machines. Specialist machines for automatic work.
British Federal Welder and Machine Co.	Jigs, fixtures and special designs.
British Oxygen Co.	Manipulators, positioners; ram-type, high lift booms, roller beds, filters, backing-bar jigs.
Courtburn Positioners	Positioners, platforms, turntables, platens, rotators, idlers, clamping machines; special manipulators.
Interlas, Ltd.	Platens, positioners.
Murex Welding Processes	Positioners and holders.
James Neill and Co. (Sheffield)	Magnetic clamps, holders, holdfasts.
Yates Plant	Manipulative equipment; backing bars.

Addresses

Associated Electrical Industries, Ltd.	Transformer Division, Heating & Welding Department, Trafford Park, Manchester, 17. *Trafford Park 2431.*
AI Electric Welding Machines, Ltd.	Grove House, Sutton New Road, Birmingham, 23. *Erdington 1176.*
Arc Manufacturing Co., Ltd.	Actarc Works, Nitshill, Glasgow, S.W.3. *Barrhead 2293.*
ARO Machinery Co., Ltd.	190 Castelnau, Barnes, London, S.W.13. *Riverside 6847.*
F. Bode & Son, Ltd.	Buxton Road, Leek, Staffordshire. *Leek 842.*
British Federal Welder & Machine Co., Ltd.	Castle Mill Works, Dudley, Worcs. *Dudley 54701.*
British Industrial Gases, Ltd.	700 Great Cambridge Road, Enfield, Middx. *Enfield 4022.*
The British Oxygen Co., Ltd.	Bridgewater House, Cleveland Row, St. James's, London, S.W.1. *Whitehall 9777.*
Centrajet, Ltd.	Fossgate, York. *York 54765.*
Courtburn Positioners, Ltd.	Kempston Hardwick, Bedford. *Kempston 2341.*
Crompton Parkinson, Ltd.	Crompton House, Aldwych, London, W.C.2. *Chancery 3333.*
Deloro Stellite, Ltd.	Stratton St. Margaret, Swindon, Wilts.
Edwards High Vacuum, Ltd.	Manor Royal, Crawley, Sussex. *Crawley 1500.*
Electrothermal Engineering, Ltd.	270 Neville Road, London, E.7. *Grangewood 9911.*
The English Electric Co., Ltd., Welding Equipment Sales & Contracts	East Lancashire Road, Liverpool. *Aintree 3641.*
The General Electric Co., Ltd.	Witton, Birmingham, 6. *East 1941.*
Hancock & Co. (Engineers), Ltd.	Progress Way, Croydon, Surrey. *Croydon 1908.*
F. Hirschman, Ltd.	Fourth Way, Exhibition Grounds, Wembley, Middx. *Wembley 5341.*
Hirst Electronic, Ltd.	Gatwick Road, Crawley, Sussex. *Crawley 25721.*
H. M. Hobson, Ltd.	Hobson Works, Fordhouses, Wolverhampton, Staffs. *Fordhouses 2266.*
Holden & Hunt, Ltd.	P.O. Box No. 17, Cox's Lane, Old Hill, Staffs. *Blackheath 1196.*
Interlas, Ltd.	Ampthill, Bedford. *Ampthill 3340.*
Kerry's (Ultrasonics), Ltd.	Special Products Group, Stud Welding Division, Warton Road, Stratford, London, E.15. *Maryland 6611.*
Lancashire Dynamo & Crypto, Ltd.	Trafford Park, Manchester, 17.
Lerche Machine Tools, Ltd.	Oakwellgate, Gateshead-on-Tyne, 8.
Lincoln Electric Co., Ltd.	Black Fan Road, Welwyn Garden City, Herts. *Welwyn Garden 4581.*
Meritus (Barnet), Ltd.	Wood Street, Barnet, Herts. *Barnet 2291.*
Messer Industrial Engineering, Ltd.	43-45 Knights Hill, London, S.E.27. *Gipsy Hill 6111.*
Murex Welding Processes, Ltd.	Waltham Cross, Herts. *Waltham Cross 23636.*
James Neill & Co. (Sheffield), Ltd.	Napier Street, Sheffield, 11. *Sheffield 26781.*
Oerlikon Electrodes (Gt. Britain), Ltd.	Kelvin Way, Crawley, Sussex. *Crawley 25971.*
Petbow, Ltd.	Sandwich, Kent. *Sandwich 3311.*
Pollock & Peel, Ltd.	82/86 South End, Croydon, Surrey. *Croydon 3158.*
Portable Welders, Ltd.	Castle Mills, Buckingham. *Buckingham 2233.*
Redifon, Ltd.	Broomhill Road, Wandsworth, London, S.W.18. *Vandyke 7281.*
Research and Control Instruments, Ltd.	207 King's Cross Road, London, W.C.1. *Terminus 2877.*
A. Reyrolle & Co., Ltd.	Hebburn, Co. Durham. *Hebburn 83-2441.*
Rockweld, Ltd.	Commerce Way, Croydon, Surrey. *Croydon 7161.*
Rowen-Arc (Division of Rubery, Owen & Co., Ltd.)	Longford Works, Blackhorse Road, Longford, Coventry. *Bedworth 2179.*
Saturn Industrial Gases, Ltd.	Erl Wood, Windlesham, Surrey. *Bagshot 2441.*
Sciaky Electric Welding Machines, Ltd.	Falmouth Road, (Trading Estate) Slough, Bucks. *Slough 25551.*
Siemens-Schuckert (Gt. Britain), Ltd.	Faraday Works, Great West Road, Brentford, Middx. *Isleworth 2311.*
Spembly, Ltd.	New Road Avenue, Chatham, Kent. *Chatham 44944.*
Suffolk Iron Foundry (1920), Ltd.	Sifbronze Works, Stowmarket. *Stowmarket 183.*
Yates Plant, Ltd. (A member of the Baker Perkins Group)	Bedewell Works, Hebburn on Tyne, Co. Durham. *Peterborough 67411.*
A. S. Young & Co., Ltd.	Tower Works, Woodside Lane, London, N12. *Hillside 6606.*

Reactivity Fluctuations in Reactor Systems

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ABSTRACT

A fundamental engineering problem of nuclear reactor systems is the analysis of the time-variation in reactivity and neutron flux distribution in the reactor core under conditions of autonomous and non-autonomous operation. This article gives an outline of four different ways in which the dynamic model of a reactor has been formulated in order to predict the time behaviour of new reactor types or to confirm the results of experiments.

THE analysis of the dynamical behaviour of reactor systems can take a diversity of forms, depending on the physical model available, the precision of the data to be used and the degree of physical insight required from the results. For example, the topological equations describing the energy changes in the system may be written down and solved long before a design has reached the drawing board stage. Space-independent, linearized transfer-functions may be used in a frequency response analysis for stability and control purposes as soon as some data are available for temperature, voidage and heat transfer coefficients. An engineering analysis, aimed at the study of the start-up, shut-down and accident transient behaviour of a nuclear power plant, usually takes place when the design has reached a fairly advanced stage.

A full mathematical study of the space and time dependent flux distribution in a reactor core is seldom undertaken until the system is actually in operation and experimental measurements become available. However, it is sometimes possible to carry out such a calculation for the subcritical prototype of the reactor lattice in question and thus acquire a feeling for the short-term, if not the long-term, reactivity and flux changes. When a reactor is finally built, it is desirable to measure its dynamical parameters, in particular the prompt and delayed neutron lifetimes, and for this a statistical technique appears to be very promising.

In all these calculations the dimensionless parameter reactivity plays an important part. Defined as

$$\rho = (k_{\text{eff}}-1)/k_{\text{eff}} \tag{1}$$

it is a measure of the flux and power levels which can be attained in a reactor. On the one hand it is a function of the nuclear parameters of the materials constituting the reactor and therefore an inherent property of any given system. This is expressed by the characteristic equation of a reactor

$$\rho = \frac{l\omega}{l\omega+1} + \frac{1}{l\omega+1}\sum_{i=1}^{m}\frac{\omega\beta_i}{\omega+\lambda_i}. \tag{2}$$

On the other hand a mechanical, thermal or hydrodynamic transient applied to the system purposely or accidentally may make a positive or a negative contribution towards the reactivity, in terms of a temperature or voidage coefficient as, for example,

$$\rho = \alpha t-\xi-\gamma[\overline{U}-\overline{U}_0]-\delta[\overline{M}-\overline{M}_0] \tag{3}$$

which expresses the reactivity in terms of rate of control rod withdrawal, change of reactivity per second, initial value of reactivity and temperature coefficients of uranium and moderator.

It is also possible to consider the reactivity as a stochastic variable and to extract a large amount of useful information[1] from the random fluctuations of a nuclear reactor by means of spectral analysis.

It is interesting and often helpful, to observe that in all these phenomena of reactivity fluctuation the nuclear reactor plays the role of a " filter " which has a response to an input signal ρ. It is the functional describing the output in terms of the input or, in vector space, the dynamical transfer matrix, which characterises a given reactor and dictates the method of solution of dynamical problems. For example, at low power, the power level of the reactor is independent of temperature, hence the kinetic equations of a reactor can be written in linear vector matrix form as

$$d\mathbf{N}/dt = K\mathbf{N}+\mathbf{S}(t). \tag{4}$$

If K is constant, then equation (4) may be Laplace transformed and has an analytical solution. If K is time varying, then the solution depends on the determination of the Green's function or impulse response of the system. In a non-autonomous system the source term $\mathbf{S}(t)$ can be modulated in three ways to provide three techniques of analysis:

(1) Time domain analysis.
(2) Frequency analysis.
(3) Statistical analysis.

For time domain analysis, the source is suddenly introduced—for example the pulsed neutron technique—and the resulting transient in N is measured. Frequency analysis requires an oscillating source or absorber. The amplitude and the phase of the response are measured. An advantage of statistical analysis[1] is that measurements can be made, without the need for expensive instrumentation, in autonomous systems. The responses obtained can be considered as being due to the least possible input signal. Hence any non-linear distortion is minimized.

Obviously such an analogy based on signal theory must not be carried too far in the analysis of a large reactor where it is essential to consider space-dependent phenomena and secular changes in fuel composition. However, it is most helpful in the consideration of control schemes, topological networks and statistical measurement.

Space and Time-dependent Analysis

For a fuller understanding of dynamical phenomena in reactor analysis a mathematical model, based either on transport theory or group-diffusion theory has to be formulated. In all except the most artificially simplified models, analytical techniques fail to give a reasonable solution and resort has to be made to numerical methods and digital computation.

The space-time approach is necessary in such contrasting problems as the calculation of long-term flux and reactivity changes in a power reactor and the interpretation of pulsed neutron measurements in a sub-critical lattice. The latter problem is particularly interesting, as it involves the study of changes in the neutron energy spectrum, as well as propagation of the pulse in space and time.

In connection with the pulsed neutron experiments being

carried out in the Queen Mary College uranium-water sub-critical assembly[2], the system of equations:

$$\frac{1}{v}\cdot\frac{\delta\phi_i(\underline{r}, u, t)}{\delta t} = \nabla\cdot D_i\nabla\phi_i - \Sigma_a\phi_i(\underline{r}, u) - \frac{\delta\eta_i}{\delta u} - \frac{\delta h}{\delta u} + S_i \qquad (5)$$

is being programmed in order to simulate space- and time-dependent behaviour. These equations incorporate the Goertzel-Selengut treatment of the slowing down problem in hydrogen. The steady state conditions are first determined by the use of a system of equations of the form:

$$-\overline{D}_i\nabla^2\bar{\phi}_i + A_i\bar{\phi}_i = S_i \qquad (6)$$

and the time integration is carried out by replacing the time derivative by the simple difference term:

$$\frac{\delta\phi}{\delta t} = \frac{\phi(r, u, t_2) - \phi(\underline{r}, u, t_1)}{t_2 - t_1} \qquad (7)$$

This system of equations enables the space- and time-dependent transients resulting from a pulse of neutrons to be computed, and also gives information on the Laplacian of the assembly and allows the transient response of the system to be studied. It is intended to apply this programme to the prediction of neutron wave phenomena, the estimation of voidage effects on reactivity and the study of neutron importance relationships by the placing of localized absorbers into the sub-critical lattice.

The reactivity fluctuation can be computed directly from a record of flux against time. A simple digital computer programme which will do this is given in Table 1.

TABLE 1

```
A → 6                  C1 = 1                 CI = CI+1
B → 6                  D1 = 0                 JUMP 4, *I-R
C → 150                J = 1(1)6              PRINT (I) 3, 0
D → 150                                       SPACE
U → *150               B = XEXP (−BJV)        PRINT (CI) 0, 4
                       D1 = AJB+D1            NEWLI*NE
HALT                   REPEAT                 JUMP 5, 50 > R
J = 1(1)6              D1 = D1+D              R = R+10
READ (AJ)                                     JUMP 4
READ (BJ)              3)C2 = U1D1+1          5)R = R+5
REPEAT                 JUMP 4                 4) REPEAT
                       7)DP = 0               REPEAT
D = 0·076043           J = 1(1)6              END
N = 1(1)2              B = X EXP(−BJV)        1)UP = 0·02V
Q) = N)                DP = DP+AJB            JUMP*6
R = 5                  REPEAT                 2)UP = XSIN*(0·3V)
I = 2(1)150                                   UP = 0·001 UP
                       DP = DP+D              JUMP 3, 3 > I
P = I-1                8)M = 1(1)P            JUMP 8
CI = 0                 K = I−M                XSIN
V = 0·1P               CI = CI+DMCKUK         XEXP
JUMP (Q)               REPEAT                 CLOSE
6) JUMP 7, I > 2
```

The decay of a neutron pulse, given off from a target at the centre of the assembly and measured by a detector placed in a suitable position, is shown in Fig. 1. Here flux (logarithmic scale) is shown as a function of time for a 50μs pulse displayed on 70 channels each 22μs wide.

A digital computer programme of similar structure may be formulated for the study of long-term reactivity changes in a reactor core. The computation of the fluxes is usually regarded as a steady-state problem. The time element is introduced by calculating the changes in the effective multiplication constant and the thermal diffusion length under conditions of long-term irradiation. An estimate of the reactivity variation can then be obtained in terms of these parameters.

The Engineering Model

The engineer is interested in the response of the reactor to normal control signals and also in the study of the behaviour of the system under abnormal or accident conditions. Use is made of a given flux distribution and neutron energy spectrum as basic data. Account has to be taken of the

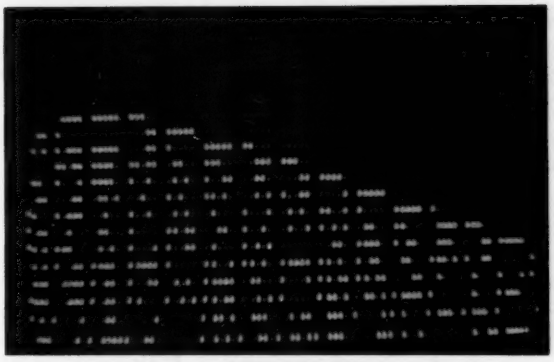

Fig. 1.—Photographic record of a neutron pulse.

complex inter-action of nuclear, thermal, mechanical and hydrodynamic transients and instabilities must be guarded against. The final consideration is usually the optimisation of the performance of the reactor by such devices as flux flattening and fuel cycling.

The physical size and structure of the reactor core usually

NOMENCLATURE

ρ = Reactivity.
k_{eff} = Effective multiplication factor.
l = Prompt neutron lifetime.
ω = Root of characteristic equation.
β_i = Fraction of total neutrons emitted per fission belonging to the i-th group.
C_i = Concentration of precursors from which the i-th group of delayed neutrons arise.
λ_i = Decay constant of fission fragments yielding delayed neutrons of the i-th group.
α = Control rod speed (ρ/sec).
ξ = Reactor shut-down negative reactivity.
γ = Uranium temperature coefficient of reactivity.
δ = Moderator temperature coefficient of reactivity.
ϕ = Thermal neutron flux.
n = Neutron density.
$\boldsymbol{N}$ = Neutron vector term.
K = Matrix characterizing neutron kinetics.
$\boldsymbol{S}$ = Source vector term.
v = Mean velocity of thermal neutrons.
D = Diffusion coefficient.
ϕ_l = Neutrons of the l-th energy group.
Σ_a = Macroscopic absorption cross section.
η_i = Slowing down density due to elastic scattering by materials other than hydrogen.
h = Slowing down density due to scattering by hydrogen.
A_i = Nuclear constants in each subinterval of finite difference system.
μ = Coefficient.
u = Lethargy.
$U(t, z)$ = Uranium temperature.
$C(t, z)$ = Coolant temperature.
$M(t, z)$ = Moderator temperature.
P = Mean heat power output at time "t."
a, b, c, d, e = Heat transfer coefficient.
θ = Temperature.
p = Coefficient of heat extraction.
q = Reactivity-temperature coefficient.
T_{sm} = Maximum can surface temperature.
T_1 = Coolant gas inlet temperature.
T_2 = Coolant gas outlet temperature.

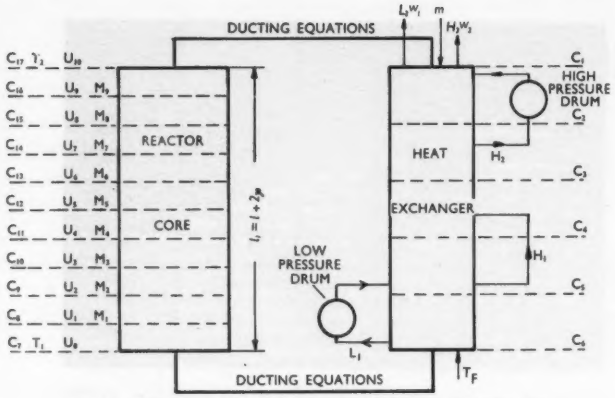

Fig. 2.—Mathematical sectioning of reactor system for start-up equations.

determines whether a space-independent, time-dependent analysis is sufficient in the simulation of the dynamical behaviour of the system. The natural uranium, graphite moderated reactor (Fig. 2) is an example of a problem where at least one space dimension must be retained in the analysis. Where the reactor core is small, as in boiling water reactors, the equations representing the dynamical behaviour of the system are often formulated for a single point in space.

There are standard methods[3] for deriving the space-independent neutron kinetic equations, but the numerical integration of the kinetic equations presents a number of unique problems. Similar difficulties may be encountered in the equations which describe nuclide decay chains, reactor burn-up and certain types of reactor control systems.

The problem is concerned with finding a numerical solution of the quasi-linear differential equation:

$$dy/dt = \mu y + F(t, y). \qquad (8)$$

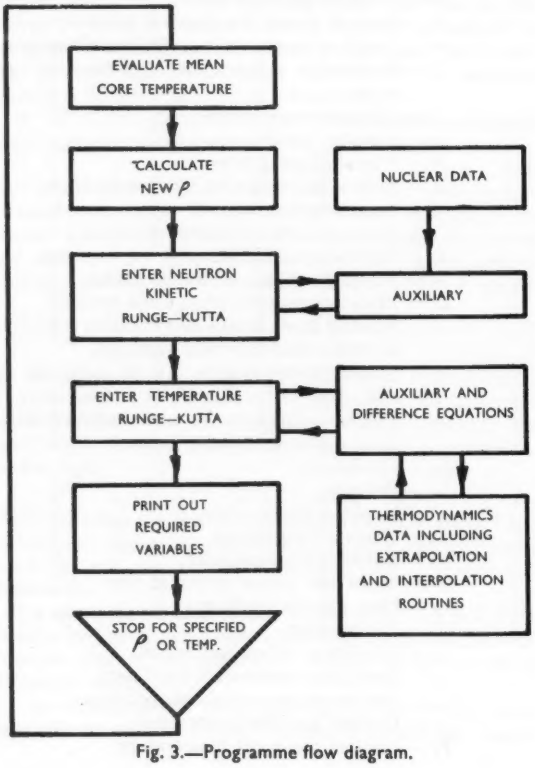

Fig. 3.—Programme flow diagram.

If μ is large the application of the usual types of numerical integration becomes cumbersome. This is because of the existence of a solution to the linearized kinetics equations whose time dependence is given approximately by $\exp(-\beta t/l)$ where β is the delayed neutron fraction and l is the neutron lifetime.

It is evident that the characteristic time l/β, which ranges from approximately 10^{-5} for fast reactors to 10^{-3} for thermal reactors, governs the size of the integration step. Unfortunately, however, for a reactor operating near criticality, control is exercised by the delayed neutrons and the time scale is very much greater. Thus thousands of time points may have to be calculated for only small changes in reactor power. This leads to inefficient computing and greater round-off and computational error.

It is possible to transform equation (8) into an equivalent integral equation which can be solved numerically with greater ease and efficiency. This is in fact done in the digital computer programme given in Table 1.

TABLE 2

$$C_7 = T_1$$
$$C_8 = T_1 + 2{\cdot}56\,[b_1(U_1 - C_7) - d_1\,(C_7 - M_1)]$$
$$C_9 = C_8 + 2{\cdot}56\,[b_1(U_2 - C_8) - d_1\,(C_8 - M_2)]$$
$$C_{10} = C_9 + 2{\cdot}56\,[b_1(U_3 - C_9) - d_1\,(C_9 - M_3)]$$
$$C_{11} = C_{10} + 2{\cdot}56\,[b_1(U_4 - C_{10}) - d_1\,(C_{10} - M_4)]$$
$$C_{12} = C_{11} + 2{\cdot}56\,[b_1(U_5 - C_{11}) - d_1\,(C_{11} - M_5)]$$
$$C_{13} = C_{12} + 2{\cdot}56\,[b_1(U_6 - C_{12}) - d_1\,(C_{12} - M_6)]$$
$$C_{14} = C_{13} + 2{\cdot}56\,[b_1(U_7 - C_{13}) - d_1\,(C_{13} - M_7)]$$
$$C_{15} = C_{14} + 2{\cdot}56\,[b_1(U_8 - C_{14}) - d_1\,(C_{14} - M_8)]$$
$$C_{16} = C_{15} + 2{\cdot}56\,[b_1(U_9 - C_{15}) - d_1\,(C_{15} - M_9)]$$
$$T_2 = C_{17}$$

$$\dot{U}_0 = -1{\cdot}712\,(U_0 - \bar{U})$$
$$\dot{U}_1 = 1{\cdot}713\,A \sin 0{\cdot}1\pi - 1{\cdot}712\,(U_1 - C_0)$$
$$\dot{U}_2 = 1{\cdot}713\,A \sin 0{\cdot}2\pi - 1{\cdot}712\,(U_2 - C_1)$$
$$\dot{U}_3 = 1{\cdot}713\,A \sin 0{\cdot}3\pi - 1{\cdot}712\,(U_3 - C_2)$$
$$\dot{U}_4 = 1{\cdot}713\,A \sin 0{\cdot}4\pi - 1{\cdot}712\,(U_4 - C_3)$$
$$\dot{U}_5 = 1{\cdot}713\,A \sin 0{\cdot}5\pi - 1{\cdot}712\,(U_5 - C_4)$$
$$\dot{U}_6 = 1{\cdot}713\,A \sin 0{\cdot}6\pi - 1{\cdot}712\,(U_6 - C_5)$$
$$\dot{U}_7 = 1{\cdot}713\,A \sin 0{\cdot}7\pi - 1{\cdot}712\,(U_7 - C_6)$$
$$\dot{U}_8 = 1{\cdot}713\,A \sin 0{\cdot}8\pi - 1{\cdot}712\,(U_8 - C_7)$$
$$\dot{U}_9 = 1{\cdot}713\,A \sin 0{\cdot}9\pi - 1{\cdot}712\,(U_9 - C_8)$$
$$\dot{U}_{10} = 1{\cdot}712\,(U_{10} - T_2)$$

$$\dot{P} = (820\rho - 6{\cdot}4066)\,P + 0{\cdot}01276\,P_1 + 0{\cdot}03504\,P_2 + 0{\cdot}1260\,P_3 + 0{\cdot}3285\,P_4 + 1{\cdot}579\,P_5 + 6{\cdot}074\,P_6$$
$$\dot{P}_1 = 0{\cdot}2243\,P - 0{\cdot}01276\,P_1$$
$$\dot{P}_2 = 1{\cdot}4739\,P - 0{\cdot}03504\,P_2$$
$$\dot{P}_3 = 1{\cdot}1531\,P - 0{\cdot}1260\,P_3$$
$$\dot{P}_4 = 2{\cdot}6007\,P - 0{\cdot}3285\,P_4$$
$$\dot{P}_5 = 0{\cdot}7944\,P - 1{\cdot}579\,P_5$$
$$\dot{P}_6 = 0{\cdot}1602\,P - 6{\cdot}079\,P_6$$
$$\rho = 0{\cdot}000003\,\dot{\tau} - 0{\cdot}07 - 0{\cdot}00002208\,(\bar{U} - 15)$$
$$\bar{U} = \frac{T_1 + T_2}{2} + 0{\cdot}8523\left[\frac{55{\cdot}5\,A}{535} + \frac{T_2 - T_1}{2}\sqrt{\left(\frac{2(T_{sm} - T_1)}{T_2 - T_1} - 1\right)^2} - 1{\cdot}052\right]$$

Compared with the care which has to be taken in the integration of the neutron kinetic equations, the treatment of the partial differential or differential equations for thermal and mechanical transients is simple. All these equations can be made to " feed-back " on the fundamental prompt neutron flux equation by means of an overall temperature coefficient of reactivity, which is one of the variables controlling the magnitude of ρ. A typical relationship in which the moderator temperature coefficient has been included, has already been given as equation (3). In homogeneous systems the reactivity is mainly influenced by fluid density effects and a second reactivity coefficient has to be defined.

For the heterogeneous system the mean uranium temperature controlling the reactivity may be obtained as a function of coolant inlet and outlet temperature, uranium can surface temperature and mean pile heat power output by means of a form of Ginns' equation. As an alternative the mean may be computed by assuming a certain coolant temperature distribution and integrating by Simpson's rule along a channel length.

The physical size of the heterogeneous system is usually much greater than homogeneous. The heat extraction from the pile is often expressed in partial differential form, a set

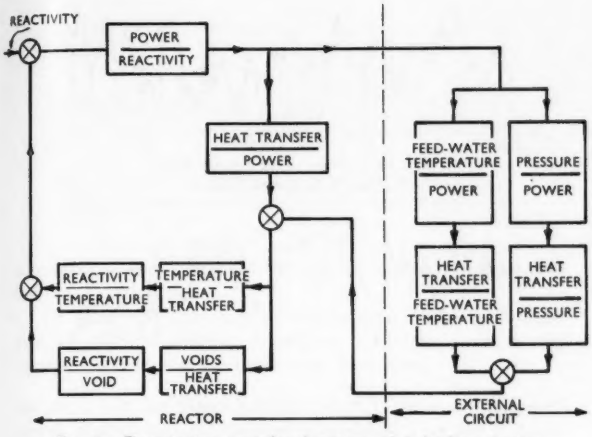

Fig. 4.—Descriptive transfer function of a boiling water reactor system.

of three equations being necessary to express the thermal transfer taking place.

$$\delta U/\delta t = (aP/P_0) \sin \pi z/l - b(U-C) \quad (9)$$

$$\delta C/\delta z = c(U-C) - d(C-M) \quad (10)$$

$$\delta M/\delta t = e(C-M) \quad (11)$$

Table 2 shows the differenced form of these equations together with the neutron kinetic equations in a form suitable for digital computer programming. A flow diagram for such a programme is given in Fig. 3. It should be noted that analogue computers may also be used to obtain solutions in start-up, shut-down and fault condition calculations.

Reactor Topology

An interesting approach to the study of reactivity fluctuation in nuclear reactor systems and to the study of reactor system stability is the use of topological analysis. Nuclear reactors have a mathematically representable physical " structure " which can be partitioned—in space as well as in time—and the behaviour of the resulting components can be described by topological methods. Thus if the component is represented by a system of differential equations or a single equation, its properties and behaviour may be studied in phase-space without actually integrating any expressions.

In the topological study of linear systems, the frequency response analysis techniques are very well known. Figs. 4 and 5 show how the dynamic " structure " of a boiling water reactor can be reduced to a series of transfer functions. The overall gain, or amplitude response of the system when subjected to a sinusoidal reactivity input, is shown in Fig. 6.

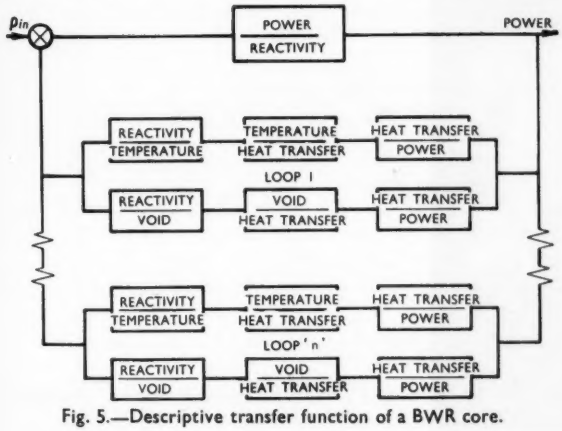

Fig. 5.—Descriptive transfer function of a BWR core.

The dynamical behaviour of nuclear reactors at high power is, in fact, far from linear. Problems can be solved in terms of the " total energy " of the system which is plotted by a semi-analytical, semi-graphical technique in the phase-space. Alternatively, as in Fig. 7, the reactor may be represented by its non-linear transfer function and solutions obtained in terms of a describing function or on a point by point basis in the time domain by convolution and distortion.

Often this more rigorous analysis of reactor dynamics leads to the detection of unsuspected peaks in the reactor transfer function which may be a sign of latent instability. These peaks or resonances are due to the presence of one or more feed-back loops which act as energy storage devices.

For the study of the non-linear dynamics of reactor systems

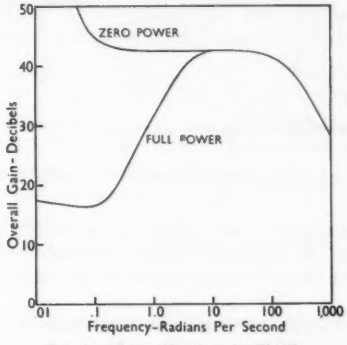

Fig. 6.—Overall gain of a BWR.

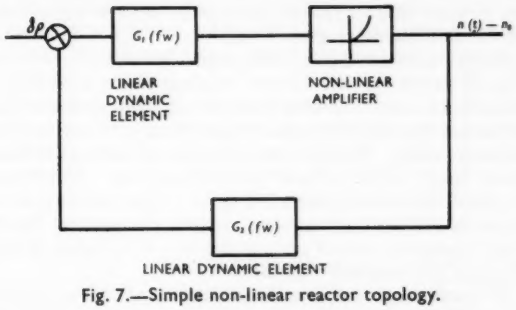

Fig. 7.—Simple non-linear reactor topology.

operating autonomously, the phase-plane technique[4] of Poincaré and Liapounoff offers interesting possibilities. The phase-space is the space of the dependent variables. The trajectory is the series of non-equilibrium states starting from an initial non-equilibrium point. Sometimes the phase-space contains singular points which are reached only after an infinite time. These equilibrium points are stable if reached at $t = +\infty$ and unstable if reached at $t = -\infty$.

The energy relationships in a nuclear reactor can be represented by three simple models:

(1) The adiabatic model.
(2) The constant power removal model.
(3) Newton's law of cooling model.

In the case of the adiabatic (no heat loss) model, the dynamic equations can be written (neglecting delayed neutrons):

$$dn/dt = \rho n/l \quad (12)$$

$$d\theta/dt = pn \quad (13)$$

$$\rho = \rho_0 - q\theta. \quad (14)$$

This system can now be plotted in phase-space according to a standard procedure to give an ensemble of trajectories as shown in Fig. 8. Each point of the phase-space is on one trajectory. The set of trajectories represents all possible solutions of the system of differential equations (12) to (14).

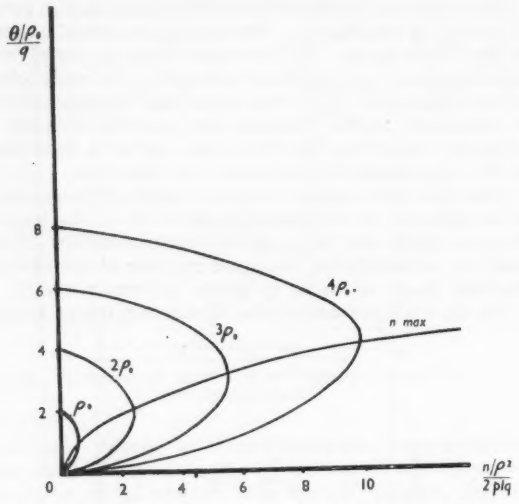

Fig. 8.—Phase-space trajectories of adiabatic model.

This technique is well suited for a preliminary stability investigation of a reactor system but becomes difficult to apply in the case of non-autonomous problems.

Statistical Measurement and Spectral Analysis

The statistical analysis of random fluctuations in reactor systems provides an interesting and powerful technique for the measurement of reactor parameters and the examination of the stability of reactor systems.

Experiments have been commenced on the Jason reactor (Fig. 9) of the Hawker-Siddeley Nuclear Power Company at Slough, on which the time-trace of the random fluctuations in neutron density of the reactor operating autonomously has been recorded. Measurements have been made at different power levels and in different parts of the core. A sample of a typical time-trace is given in Fig. 10. This noise waveform contains sufficient information to plot the reactor transfer function and to deduce such parameters as effective neutron lifetimes and reactivity coefficients.

A portion of the amplitude spectrum of the random fluctuation is given in Fig. 11 and the spectral density of the random fluctuation in Fig. 12. The method is being

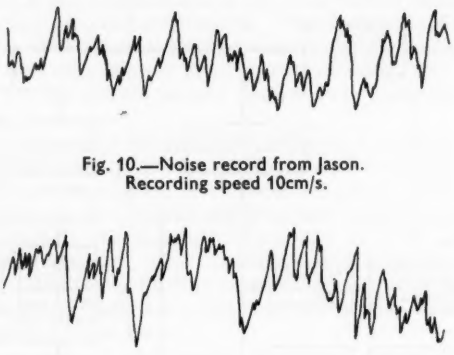

Fig. 10.—Noise record from Jason.
Recording speed 10cm/s.

extended to multi-channel measurements on the basis of which it will be possible to cross-correlate the data to determine the values of spatially dependent reactor parameters.

These statistical techniques are by no means limited to measurements at low power in research reactors. Fig. 13 shows a record of small power oscillations in a boiling water reactor. Data of this form can be correlated either digitally or analogue-wise and useful information gained as to reactor parameters and system stability. An alternative approach is to set up the complete set of dynamic equations of a system (as in Table 2) either on an analogue or a digital computer and to " drive " the equations with Gaussian noise. In this way the resonant frequencies of nuclear, thermal and hydrodynamic parameters in all loops of the reactor system should become apparent and an estimate can be made of their true value under dynamic conditions.

One other aspect of the stochastic dynamics of reactor systems is being investigated in the Nuclear Engineering Laboratory of Queen Mary College. In parallel with the pulsed neutron work it is planned to measure the " impulse response " of reactor systems by using a stochastic input. This is analogous to the well-known pile-oscillator technique with the exception that the oscillator drive is now actuated by a periodic binary input signal. Such a signal has been produced in the laboratory using a radioactive source and a Geiger counter and binary counting circuit combination. If the input and the output are cross-correlated the inpulse response of the reactor system can be determined.

The statistical approach to reactor dynamic problems has

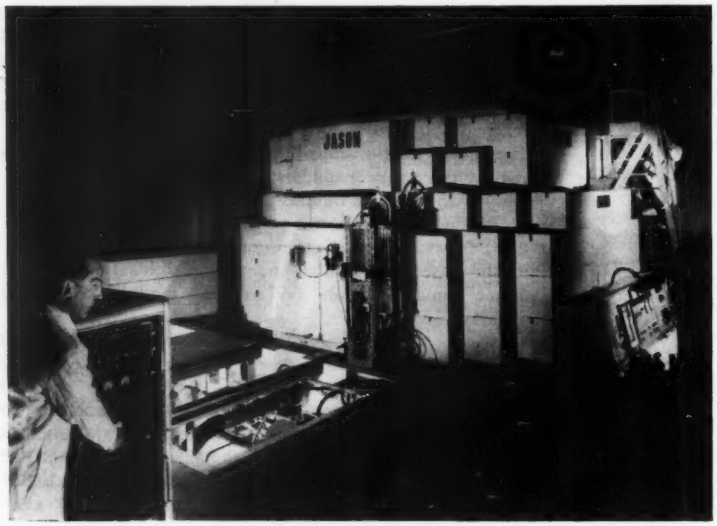

Fig. 9.—The Jason research reactor. (Hawker-Siddeley Nuclear Power Co., Ltd.)

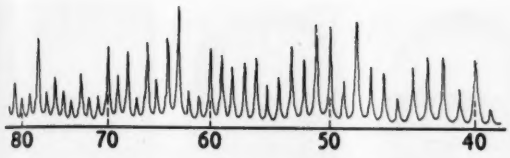

Fig. 11.—Amplitude spectrum of random fluctuation showing peaks from 40th to 80th harmonic of spectrum.

a number of important advantages, some of which are listed below:

(i) The technique most closely approximates to " small signal " theory. Hence non-linear distortion effects are minimized, and the reactor kinetic equations

$$dn/dt = (\rho-\beta)n/l + \sum_{i=1}^{6} \lambda_i C_i \qquad (15)$$

and

$$dC_i/dt = \beta_i n/l - \lambda_i C_i \qquad (16)$$

approximate to a set of linear differential equations with constant coefficients and give the reactor transfer function:

$$\frac{\Delta n_o(j\omega)}{n_o} \Big/ \frac{\Delta\rho(j\omega)}{\beta} = 1/(j\omega)(l/\beta)\left[1+\sum_{i=1}^{6}\frac{\beta_i/\beta}{l/\beta(j\omega+\lambda_i)}\right] \qquad (17)$$

(ii) The instrumentation is relatively cheap.

(iii) Measurements can be made under operational conditions with little disturbance to the flux or the control instrumentation and with no possibility of the introduction of dangerous conditions (Fig. 14).

Conclusions

Each of the four reactor models proposed in this article gives a different insight into the dynamical behaviour of nuclear reactor systems. From an engineering point of view each leads to practical techniques in nuclear reactor system design and utilization.

A space and time-dependent analysis is unavoidable when the investigation concerns secular changes in the core composition or the propagation or dispersion of nuclear transients.

An engineering " analogue " of the reactor system is useful in the study of start-up problems and in safety calculations.

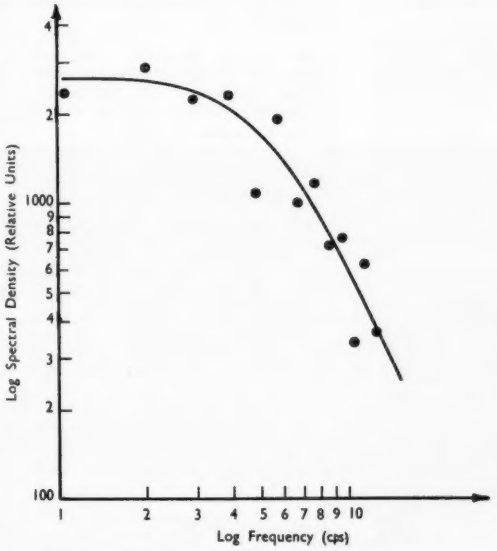

Fig. 12.—Spectral density of random fluctuation.

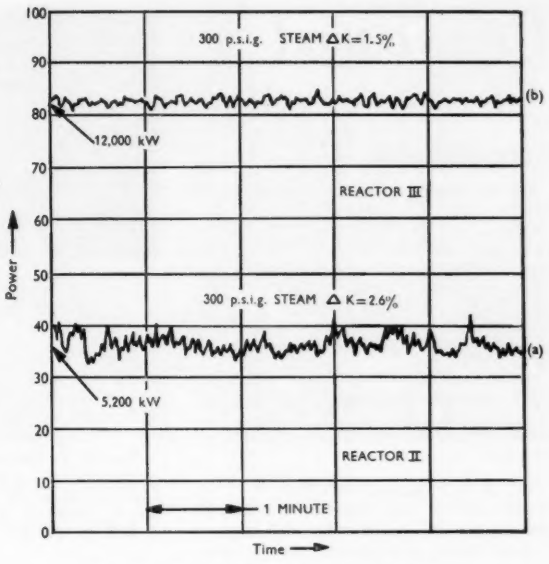

Fig. 13.—Power fluctuation in two BWRs.

The equations to be solved are usually descriptive rather than true representations of physical pressures.

The phase-space technique in reactor topology gives an insight into the problem of the stability of non-linear autonomous reactor systems. Quantitative topological methods facilitate the study of linear and non-linear reactor control problems.

For the measurement of reactor parameters under operating conditions either on the real or the simulated reactor system, statistical methods and spectral analysis offer attractive possibilities.

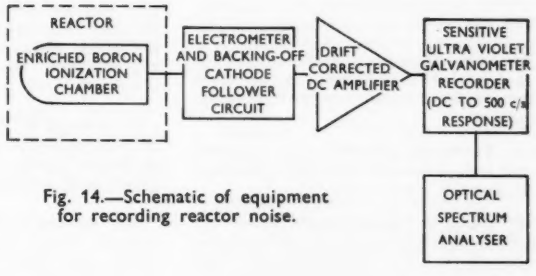
REACTOR
ENRICHED BORON IONIZATION CHAMBER
ELECTROMETER AND BACKING-OFF CATHODE FOLLOWER CIRCUIT
DRIFT CORRECTED DC AMPLIFIER
SENSITIVE ULTRA VIOLET GALVANOMETER RECORDER (DC TO 500 c/s RESPONSE)
OPTICAL SPECTRUM ANALYSER

Fig. 14.—Schematic of equipment for recording reactor noise.

ACKNOWLEDGMENTS

The author wishes to record his grateful thanks for permission to carry out experiments on the Jason reactor of the Hawker Siddeley Nuclear Power Company at Slough, in collaboration with one of his students, Mr. Samaun. Fig. 1 is published by kind permission of Dr. W. K. Mansfield and Mr. J. M. Kim and is one of a series taken during recent pulsed-neutron experiments taken in the Nuclear Engineering Laboratory of Queen Mary College. Figs. 4, 5 and 6 are extracted from a student project by P. R. Smith and M. J. Neeves. The interest and partial support of this project by the U.K.AEA is gratefully acknowledged.

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3. Glasstone, S. and Edlund, M. C. " The Elements of Nuclear Reactor Theory." Van Nostrand, 1952.
4. Ergen, W. K., Lipkin, H. J. and Nohel, J. A. " Application of Liapounoff's Second Method in Reactor Dynamics" J. Math. Phys., **36**, 36-48 (1957).

Personal

Appointments—U.K.

Mr. St. John de H. Elstub, joint managing director of ICI Metals Division, as chairman, and **Dr. W. H. G. Lake,** as joint managing director (technical). Mr. Elstub succeeds **Mr. M. J. S. Clapham,** who has joined the company's main board as an overseas director. Dr. Lake has been with ICI since 1940, and between 1943 and 1952 was engaged in nuclear energy work on behalf of the Government.

Mr. Anthony M. Browne, chairman and managing director of Hackbridge and Hewittic Electric Co., as president of BEAMA.

Mr. H. H. Mullens, chairman of C. A. Parsons and Co., and chairman and managing director of A. Reyrolle and Co., as BEAMA deputy president.

Mr. E. C. Rippon, chief transformer engineer, C. A. Parsons and Co., as a director.

Mr. N. E. N. Plahn, to the board of Hawker Siddeley Industries.

Mr. John Black, deputy chairman of Metal Industries, as managing director, and **Mr. Wilfred Padley,** formerly managing director of Brookhirst Igranic, one of the Metal Industries subsidiaries, as deputy managing director.

Mr. J. O. Bovill, as managing director of Wolf Sales Pty., New South Wales, the Australian associated company of Wolf Electric Tools.

Mr. J. C. T. Fell, export sales manager of Ferodo, as export sales manager of Turner Brothers Asbestos Co.

Mr. F. R. Allen, an executive director of Firth Cleveland Instruments, is to be in charge of the company's sales engineering department.

Mr. V. M. G. Bennett, chief executive of the bellows division of Teddington Aircraft Controls, to the board.

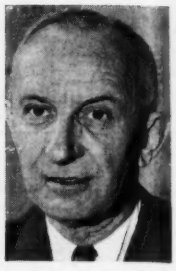
Mr. James R. Beard, senior partner in Merz and McLellan, the consulting engineers, as president of the British Electrical and Allied Industries Research Association.

Mr. Stanley Jessop, as manager of the Scotstoun works of Thos. W. Ward.

Mr. St. J. de H. Elstub.

Dr. W. H. G. Lake.

Mr. E. C. Rippon.



Mr. H. L. Price.

Mr. D. A. Birch, who for the past four years has been responsible for optimizing on nuclear power station design for John Thompson, as PRO for the J.T. group.

Mr. H. V. Stammers as acting chairman of International Computers and Tabulators, Ltd., following the death of Sir Cecil Weir. **Mr. C. Mead** as deputy chairman and **Mr. J. Bull** as managing director.

Overseas

Mr. Harold L. Price, director of the U.S.AEC division of licensing and regulation, as acting director of the newly created regulation division. This is the first appointment following the announcement that certain AEC divisions are being reorganized (see "World Digest").

Dr. Raja Ramanna, head of the nuclear physics division at Trombay, India, as chairman of the joint IAEA-Norwegian research management committee that is to run the zero energy reactor Nora at Kjeller ("World Digest," March and April). Other members of the committee are **Dr. Pierre Balligand,** recently appointed deputy director-general of the IAEA in charge of technical operations; **Dr. Carlo Salvetti,** IAEA director of research and labaratories, **Mr. Olav Kasa,** project manager of the HBHWR and assistant director of the Norwegian Instituut fur Atomic Energy, and **Dr. Henrik Ager-Hansen,** reactor physicist on the Halden project.

Dr. Kenneth W. Newman, general manager of Isotopes Specialties, Burbank, California, as director of sales engineering, Nuclear Corporation of America.

Mr. Edward F. Weisner, Atomics International project engineer for the Piqua OMR power plant, as project engineer for the preliminary design of the proposed KBWP OMR project in Germany. His successor on the Piqua plant is **Mr. Jack Jacobson.**

Dr. J. A. Goedkoop, head of the physics department of Reactor Centrum Nederland, as managing director of research.

Mr. Dennis Pearce, manager of chemical effluents technology at the General Electric works, Hanford, U.S.A., as IAEA director of health, safety and waste disposal; **Senor Sanchez del Rio,** head of the physics division and a director of the Junta de Energia Nuclear, Spain, as chief of the IAEA reactors division; **Mr. Costmir Simano,** deputy director of the Institute of Nuclear Research, Rez, Czechoslovakia, as IAEA director of technical supplies; and **Dr. Dragoslav Popovic,** assistant to the secretary-general of the Federal Nuclear Energy Commission of Yugoslavia, as IAEA director of safeguards.

Mr. E. W. L. Ginkel, formerly director of the operations division, U.S.AEC Idaho Falls Operations Office, as assistant manager, technical operations. In this newly established post Mr. Ginkel will be responsible for certain Idaho Falls Operations Office functions at the National Reactor Testing Station. Other new IOO appointments include those of **Mr. Earl W. Bosse,** director of engineering at the AEC Lockland Aircraft Operations Office, as director of reactors; **Mr. Klem K. Kennedy,** chief of the chemical processing branch, as director of the chemical processing and development division; and **Mr. W. A. Erickson,** one time director of technical operations and then chief of the contract administration branch, as director of the contract administration division.

Mr. T. A. Bedford, vice-president in charge of engineering and construction project development for Kaiser Engineers, as president and director of the Henry J. Kaiser Company (Canada).

Retirements

Mr. Edgar Stott, as export sales manager of Turner Brothers Asbestos Co., after 42 years' service with the company.

Mr. Charles Grad, as university liaison officer for Associated Electrical Industries and education consultant. He was until the end of 1959 manager of the education department, Rugby. Mr. Grad joined BTH in 1920.

Mr. H. L. Satchell, as director of manufacture, Associated Electrical Industries (Rugby), after 41 years' service.

Resignation

Mr. J. E. Griffiths, from the board of Teddington Aircraft Controls.

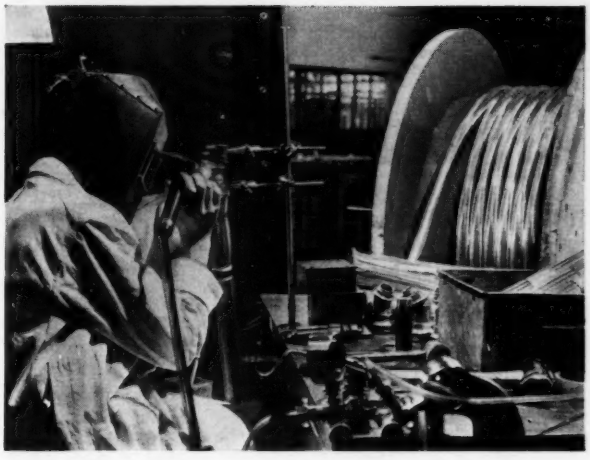
Mr. E. W. L. Ginkel.

Dr. J. A. Goedkoop.

Dr. C. Salvetti.

Dr. K. W. Newman.

Industrial Notes



An operator welds the end fittings to an 80 ft length of dual bore stainless steel flexible hose destined for use with a television camera inside a Chapelcross reactor. The cable is supplied by Power Auxiliaries, a member of the Plessey Group.

Laurence Scott and Electromotors, of Norwich, are to design and manufacture the electric propulsion machines and switchgear for Britain's second nuclear submarine.

Sames, of Grenoble, France, have formed a British subsidiary, at Acton, London, but this in no way affects the arrangements the company have with **Miles Hivolt,** of Shoreham-by-Sea for the marketing of their accelerators. Its main function is the handling of electrostatic paint equipment. Miles Hivolt recently delivered to the AEA at Windscale a 250 keV 7 milliamp portable accelerator for use as a neutron source for AGR zero energy work.

John Laing Construction are shortly to start work on the building of a seven-storey office block at Windscale. It is due for completion by July, 1962.

FBI London and South Eastern Region have initiated a scheme for the sharing of scientific equipment between member companies. They have circulated a list of equipment which companies are prepared to make available to others and a list of equipment to which companies would like to have access.

A conference on exports is to be held by **BEAMA** on October 5-6 as part of the Association's special golden jubilee activities.

AEI-Birlec have formed in conjunction with Major Electric Furnaces Pty., of Australia, a new company—Birlec-Major Pty.—for the manufacture and marketing in Australia, New Zealand and S.E. Asia of Birlec products. Offices of the new company are in Chesterville Road, Moorabbin, Melbourne.

The Electrical and Electronic Manufacturers Joint Education Board states in its first annual report that suitable topics for discussion at a conference for industrial training officers to be held in the autumn are now under consideration. The Board hopes that such a conference will become an annual event.

Delapena and Son, of Cheltenham, Glos, are to take over the servicing of English Electric R.F. induction heaters with effect from June 1. English Electric have given up their activities in this field and are supplying Delapena with adequate stocks of suitable spares.

Edwards High Vacuum, of Crawley, Sussex, have been appointed sole U.K. and Commonwealth agents for the Danish " Reciprotor " combined vacuum/pressure pump.

Nearly 500 exhibits will be on show at the **5th Annual Midlands Instrument and Controls Exhibition** at the Central Y.M.C.A., Birmingham, April 25-28. Concurrent with the exhibition will be a series of lectures.

Dewrance and Company have formed a Metals Division embracing the foundry at Hillington and the special alloys division, London. It will deal with the company's production and sales of non-ferrous castings and nickel, stainless steel and high temperature brazing alloys.

The Morgan Crucible Company has ceased to be a trading company and its product departments have been formed into new subsidiary companies. These are Morganite Carbonite, Morganite Crucible, Morganite Electroheat and Morganite Research and Development.

The Distillers Company, Chemical Division, have produced a new film on safety precautions in the handling of highly flammable materials. It runs for 16 minutes and is available in 16 mm on free loan.

The U.K.AEA are to exhibit at the Achema exhibition, Frankfurt, June 9-17.

Flexibox, manufacturers of mechanical seals, of Manchester, have formed in conjunction with their Dutch agents, a new company—Flexibox N.V. Headquarters are at Noordeinde 18a, The Hague.

Blackhawk, of Acton, London, have formed a new division—Power Packer—to meet the demand for simple hydraulic equipment on a quantity basis.

Société Rateau, Paris, are supplying a gas circulator for out-pile experiments to be carried out for the Dragon project at the Parsons nuclear laboratories, Newcastle. A research and development contract to explore the potentialities of Rateau's " multi-shoes gas bearing " is under discussion with the Dragon project organization.

The Australian Government is making additional rewards totalling £14 000 for uranium discoveries. The syndicate which discovered Anderson's Lode, in the Mount Isa district, and which has already been paid £1 000 is to receive a further £9 000. £4 500 is to paid to the syndicate responsible for discovering the Skal lease, for which they have already received £500. Discoverers of the Killi Killi prospect are to receive £500.

Tracerlab, of Waltham, Massachusetts, are to supply radiation monitoring instrumentation for the PM-1 plant.

Pneumo Dynamics, of Washington, D.C., have been awarded a $200,000 contract for the development and fabrication of equipment to be used in study of the mixing, diffusion and circulation of oceanic waters for radioactive waste disposal purposes (see " World Digest ").

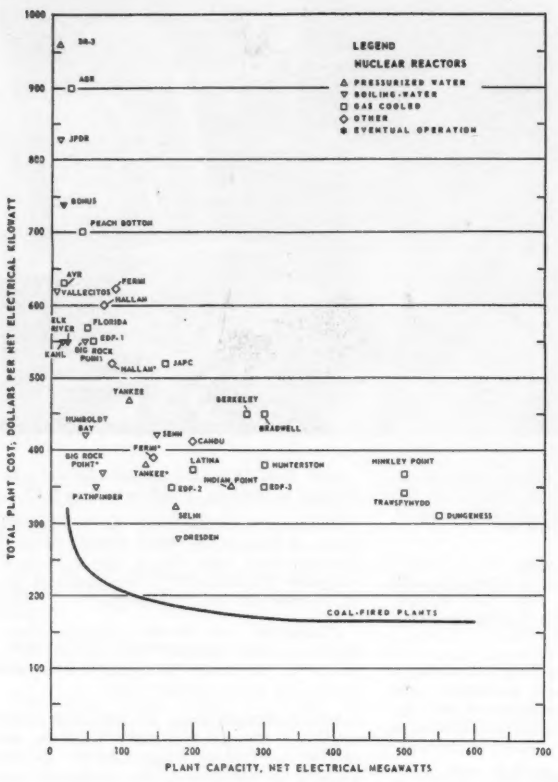
Spencer Chemical Company of Kansas City, have received an order for two tons of 3.7 % enriched uranium carbide to be supplied to Atomics International. It will be used in prototype fuel elements for the Hallam, Nebraska, sodium graphite reactor.

Aerojet-General Corporation's nuclear propulsion division, California, have received a $500 000 Air Force contract for nuclear engine research. It covers a study design for nuclear propulsion systems ranging from the upper stage thrust levels to multi-million-pound thrust boosters.

Nuclear Enterprises of Canada, have moved to new and larger premises at 550 Berry Street, Winnipeg 21. Telephone: Spruce 4-1991/2.

Temple Press Limited, publishers of *Nuclear Engineering*, at the 1961 Electrical Engineers' Exhibition, Earls Court, London.

Technical Papers and Publications



Costs of various reactors compared with coal-fired plant. (From TID-8531.)

U.S. AEC

TID-8531. Costs of Nuclear Power. Milton F. Searl, Donald W. Kuhn, Paul C. Fine, George Y. Jordy and Ray D. Walton of the AEC Office of Operations Analysis and Forecasting. (Office of Technical Services, Department of Commerce, Washington 25, D.C. $0.50.)

This 40-page report replaces an earlier report of the same title, which was published in 1959 as TID-8506, and includes information on several new reactor projects, and general revision of figures up to the third quarter of 1960.

In the space available, it is not possible to do more than indicate the scope of the report, which has nine major headings. First, research and development costs are tabulated for a number of specific U.S. plants, after which reported construction costs are given under different types of reactors, for a number of U.S. schemes, including export plants such as SELNI and SENN, these costs being classified under figures for land rights, structures and improvements, reactor plant, steam plant, miscellaneous plant, interest during construction, additional indirect construction costs, contingencies and escalation.

Possibly the most interesting portion of

TABLE 1—REPORTED CONSTRUCTION COSTS (Extracted from Table 4 of TID-9531)

Plant	Net capacity MW(e)	Total cost $M	Cost $/kW
Pressurized Water			
McMurdo Sound (a)	1·5	5·6	3 730
SM-1	1·9	3·9	2 050
Saxton (b)	3·25		
APS-1 (U.S.S.R.) (c)	5·0		
BR-3 (Belgium)	10·7	10·3	960
Shippingport (d)	60·0	72·9	1 220
Yankee	110–136	52·0	470–380
SELNI (Italy)	176·0	56·4	320
Voronezh (U.S.S.R.)	196×2		
Indian Point (e)	255·0	89·5	350
Boiling water			
EBWR (f)	4·5	4·6	1 020
Vallecitos (g)	5·0	3·1	620
JPDR (Japan)	11·2	9·7	830
Kahl (W. Germany) (h)	15·0	8·3	550
BONUS (i, j)	16·3	12·1	740
Elk River (k)	22·0	12·2	550
Humboldt Bay (j)	48·5	20·6	420
Big Rock Point (i)	48·5–72·8	26·7	550–370
Ulyanovsk (U.S.S.R.) (m)	50·0		
Pathfinder (n)	62·0	21·8	350
Byeloyarsk (U.S.S.R.)	94×2		
SENN (Italy)	150·0	63·2	420
Dresden (o)	180·0	51·0	280
Gas cooled			
AVR (W. Germany) (p)	15·0	9·5	630
EGCR (q)	22·3	30·6	1 370
AGR (U.K.)	27·3	24·6	900
Peach Bottom (r)	40·0	27·8	700
Florida (s)	50·5	28·6	570
EDF-1 (France) (t)	60·0	33·0	550
Neuglobsow (E. Ger.) (u)	70·0		
Berkeley (U.K.)	137·5×2	123·0	450
Bohunice (Czech.) (m)	150·0		
Bradwell (U.K.)	150×2	134·0	450
Hunterston (U.K.)	150×2	115·0	380
JAPC (Japan)	158·0	85·6	540
EDF-2 (France) (v)	170·0	59·0	350
Latina (Italy)	200·0	73·0	370
Hinkley Point (U.K.)	250×2	186·0	370
Trawsfynydd (U.K.)	250×2	172·0	340
Dungeness (U.K.)	275×2	169·0	310
Sizewell (U.K.) (y)	290×2	154·0	270
EDF-3 (France)	300.0	104·0	350
Heavy water cooled			
Carolinas-Virginia (w)	17·0	17·7	1 040
NPD-2 (Canada)	20·0	30·3	1 520
CANDU (Canada)	200·0	81·5	410
Organic			
Piqua (x)	11·4	11·8	1 040
Sodium graphite			
SRE	5·7	8·6	1 510
Ulyanovsk (U.S.S.R.) (m)	50·0		
Hallam (j)	75–87	45·0	600–520
Fast breeder			
Dounreay (U.K.)	12·0		
EBR-II	17·4	25·3	1 450
BN-50 (U.S.S.R.)	50·0		
Fermi	91–143	56·3	620–390

(a) Cost given includes shipping the unit to Antarctica and erection there.

(b) Contract price of $6·25 million includes cost of fuel for five-year period of operation, but does not include cost of land, turbogenerator unit, or other pre-existing facilities.

(c) Graphite moderated.

(d) Present plans for core 2 are to increase gross capacity of plant to 100 MW(e) (limit of existing turbine-generator) and, in addition, absorb the thermal equivalent of 50 MW(e) in a heat sink, at a cost of about $9 million for plant modifications and the heat sink.

(e) Superheating with oil contributes 104 of the net 255 MW(e).

(f) Electrical capacity is limited by the size of turbine-generator. Cost of recent conversion to 100 MW(th) is not included.

(g) Incremental cost at Vallecitos Atomic Laboratory, not including cost of recent modifications. Cost includes fabrication of first core. Electrical capacity is limited by size of turbine-generator.

(h) Cost given includes training of operating personnel and $0·2 million already spent for planned plant extension to 30 MW(e), but does not include site purchase and preparation or interest during construction.

(i) Nuclear superheat contributes 13 to 50 MW(th).

(j) Total costs used here for BONUS, Humboldt Bay, and Hallam are the recent estimates given in footnotes of Table 2.

(k) Superheating with coal contributes about 7 of the 22 net MW(e).

(l) Net capacity has been estimated for purposes of this report at 97 per cent of gross capacity.

(m) The number of electrical megawatts given probably represents gross rather than net capacity of the plant.

(n) Nuclear superheat contributes about 17 of the 62 net MW(e).

(o) Cost given includes contract price of $45 million, cost of land at $0·55 million; and overhead and interest during construction at $5·6 million.

(p) Cost given includes fabrication of first core.

(q) Cost given includes construction and installation of large experimental loops for test irradiations.

(r) Graphite-clad fuel elements.

(s) Cost does not include heavy-water inventory.

(t) Up to 68 net MW(e) has been reported.

(u) Heavy-water moderated. The number of electrical megawatts given probably represents gross rather than net capacity of the plant.

(v) Up to 198 net MW(e) has been reported.

(w) Cost given does not include heavy-water inventory or pre-existing turbine-generator. Superheating with oil contributes 10 of the 60 MW(th).

(x) Cost includes turbogenerator unit rated at 33 MW(e) and complete structure for an additional turbogenerator unit, although the gross capacity of the plant as designed is only 12·5 MW(e).

(y) Costs given are based on information that the value of the contract with the consortium of companies building the station is of the order of 55 million pounds sterling.

the report is the third, which gives the total costs of more than 50 plants of U.S. and other nations, classified according to the type of reactor; figures are given of total cost and cost per net kW of electrical output, except in certain cases where information has not been made available. An extract from this section is given in Table 1.

A further section briefly reviews working capital, and the difference between nuclear and fossil fuel stations; this is further emphasized in the next section, which deals with annual fixed charges.

Fuel-cycle costs are considered at some length, and a table lists first cores for 28 U.S. reactors, with particulars of element dimensions, enrichment, total loading, and fabrication costs per kg, this last showing a variation ranging from $48 for the 0·35% enriched U-Mo elements for the Fermi blanket, to the truly fantastic cost of $26 000 for the 93% enriched U-Zr seed 2 elements for Shippingport. Costs of chemical processing are also considered, along with charges for leased fuel, and Pu-credit. Estimated total fuel cycle costs for a Yankee-

TABLE 2. COMPARISON OF NUCLEAR AND FOSSIL-FUEL GENERATING COSTS PER NET KW OUTPUT

	Nuclear	Fossil
Construction cost $/kW	300–400	150–200
Plant factor	80%–70%	80%–70%
Cost (mill/kWh)		
Fixed charges on construction cost	6·5–10·0	3·0–4·5
Fuel costs	3·5–5·5*	2·0–4·0†
Operation and maintenance	1·0–2·0	0·5–1·0
Total	11·0–17·5	5·5–9·5

* Includes cost of fuel cycle and fixed charges on investment in fuel fabrication.
† Based on fossil-fuel costs of 20–40 c per million Btu, and a plant heat rate of 10 000 Btu/kWh s.o.

type PWR, are tabulated for various irradiation levels and initial enrichments; at 2 500 MWd/t the cost is given as 11 mill/kWh, reducing to 3·96 at 10 000 MWd/t, and to 2·58 at 25 000 MWd/t.

Following a section dealing with costs of operation and maintenance (including employee training) an attempt is made to estimate total costs for comparison purposes. The difficulties and uncertainties of this are well known but, based on a PWR or BWR of around 150 MW net capacity, with 15% annual fixed charge on construction costs (14% for fossil fuel stations) 11% annual fixed charge on fuel fabrication investment, and 4% use charge on the uranium inventory, the comparison is given in Table 2. The report concludes with a statement of objectives for competitive nuclear power in the U.S., and a list of owners and operators of nuclear plants.

TID-8200 (3rd Rev.) Nuclear Reactors Built, Building, or Planned in the United States, as of December 31, 1960. (Office of Technical Information Extension, U.S.AEC, P.O. Box 62, Oak Ridge, Tennessee (no charge).)

This publication is revised semi-annually, the December tables being repeated in the AEC's annual report. It gives a complete list of all the reactors in the U.S., under five main headings—civilian, military, production, reactors for export, critical assembly facilities. Various sub-divisions of these classes are recognized, and definitions of these are listed showing, for example, the differentiation between a reactor experiment and an experimental reactor. A statistical summary showing the number in the first four main categories shows that the U.S. has 20 reactors dismantled, 166 operable, 125 being built, and 36 in the planning stage. There is also a list of contractors, designers, shipbuilders and facility operators referred to in the tables.

THE INSTITUTION OF MECHANICAL ENGINEERS

(Nuclear Energy Group)

Design of Irradiation Experiments. By J. R. Atkinson, B.Sc., Ph.D., and S. Rigg, B.Eng. (Paper read at a meeting at the Clarendon Laboratory, Oxford.)

This paper gives a general idea of the necessity for in-pile testing, and some of the problems involved in studying irradiation tests by means of experimental loops. An irradiation experiment demands closely integrated team work over eight phases which, after the establishment of the need for a particular experiment, might be summarized as basic specification and feasibility study; detail specification, preliminary safety study, and basic drawings; detail manufacturing drawings; manufacture; out-of-pile tests and final safety study; irradiation; dismantling and interpretation of results.

Emphasis is placed on deciding, in the early stages, not to attempt too much, which might require drastic modification of the design at a later date, or the expenditure of an effort out of all proportion to the results. An example of this is given later in the paper in an account of a loop for investigating mass transfer of liquid metal. The flow velocity originally selected was 6 ft/sec. This was later reduced to 2 ft/sec, which reduced the diameter from 23 in to 10 in, the protruding length from 9 ft 7 in to 2 ft 10 in, and the shielding weight from 108 tons to 5 tons. This was an excellent example of the need for the closest co-operation between the scientist and the engineer.

Since both the authors have been closely connected with the DMTR test reactor at Dounreay, the paper dealt almost exclusively with reactors of this type, and five types of loop were described. These were:—

A semi-static carbon dioxide experiment to determine the behaviour of graphite, etc., irradiated in CO_2 at high temperature and pressure.

A graphite-CO_2 dynamic mass transfer experiment.

A liquid metal mass transfer experiment.

A water-cooled fuel specimen experiment.

A gas-cooled fuel element experiment (actually for the AGR).

Before the detail description of the various experiments, some idea was given of the design calculations required, and the importance of ensuring correct conditions, including fast and thermal neutron fluxes, gamma flux, temperature, coolant composition and velocity, Reynolds numbers and, in the case of fuel elements, rating and burn-up. Considering fluxes, the authors pointed out that fast and gamma fluxes in a reactor would be little affected by the presence of a loop, whereas thermal neutron flux would be considerably depressed. Methods of flux calculation were given, and it was pointed out that calculations could be made to within 10%, the measured flux from which this was determined would have an accuracy of 5% and, allowing for variation in loading, burn-up, and power, the accuracy would only be within 20%.

Certain experiments in DMTR would be repeats of work already carried out in DIDO, and used for comparing the two reactors. In this connection, it was interesting to note that the unperturbed gamma flux in DIDO was considerably higher than that in DMTR, due to the geometrical differences in the reactors; the actual figures given being $1·3 \times 10^{14}$ and 6×10^{13} photons/cm²sec, respectively.

THE INSTITUTE OF METALS

Compatibility Problems in Gas Cooled Reactors. (Part of Symposium held at Spring Meeting.)

This session was only sparsely attended and this may have contributed to the absence of any really incisive discussion on current problems. The session was opened by three formal papers by Dr. Tyzack of Culcheth, Dr. Knapton of AEI Aldermaston, and Dr. Baird of the NPL. In the first a summary was given of the results obtained by the AEA on the corrosion of magnox and the oxidation of uranium but unfortunately, time did not permit the oxidation of graphite to be included. Dr. Knapton and Dr. Baird were more concerned with the mechanisms of corrosion and with the interpretation of present results. It was suggested that there was need for an intensive study to be made of the UO_2-beryllium solid reaction as extrapolation of existing results indicated that if the two materials are left in contact at 600°C for two years a reaction product thickness of 50 u m would have developed. A brief contribution from M. Loriers reviewed some of the compatibility problems in the EL-4, pressure tube, CO_2 cooled, heavy water moderated reactor being built at Morlaix.

Designs for this reactor provide for a coolant pressure of 60 atm, fuel elements of natural uranium canned in beryllium (although initially, enriched uranium and stainless steel canning will be employed), pressure tubing of Zircaloy, thermally insulated, a gas inlet temperature of 260°C and outlet temperature of 500°C. It has already been concluded that the maximum can surface temperature with beryllium must be limited to 600°C and at present the stainless steel is limited to 630°C. An examination of the most suitable stainless steels for canning (thickness 0·4 mm) has shown that type 347 is most suitable for a strong can but type 304L may be used eventually for a deformable can.

In experiments on beryllium in a CO_2 atmosphere break away phenomena have been observed at 650°C and 700°C but at 600°C this has not been observed.

For the main body of the circuit it is concluded that austenitic stainless steels would be too expensive and whilst 0·5%Cr/0·5%Mo and 2·25%Cr/1%Mo steels have adequate mechanical properties in the temperate range 500-525°C the corrosion rate in CO_2 appears critical.

The oxidation rate for low alloy steels can be represented by the equation: $\Delta m = kt^n$ where Δm is the weight gain per unit surface area, t is the time, k is a constant and n is a variable generally lower than 0·5. Using this formula the two low alloy steels quoted would be satisfactory at 500°C but any cracking of the oxide film would enhance the rate. At 525°C irregular attack appears after 800 hours. Aluminium additions improve the oxidation resistance but little experience has been obtained on steels of this type. An 11%Cr/1%Mo steel with additions of vanadium and niobium shows good oxidation resistance in CO_2 up to 700°C and it is possible that a steel with a chromium percentage betwen 5 and 11 may be necessary.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 845,306. Nuclear reactor moderator structures. W. Rodwell. To: U.K. Atomic Energy Authority.

The structure is suitable for installation in a ship. Uniform right prismatic graphite blocks are positioned in layers defining coolant channels parallel to their length. The blocks have minimum Wigner growth properties in the direction of their length. Layers of graphite tiles alternate with the layers of blocks which provide coolant channels continuous with the block channels. The tiles touch one another on all their side faces, each tile has minimum Wigner growth properties in a direction which is perpendicular to the longitudinal axes of the blocks and to the direction of minimum Wigner growth in tiles adjacent to its side faces. The tiles are wider than the blocks in the direction of minimum Wigner growth in the tiles and they are keyed to the blocks.

B.P. 845,456. Fuel element discharge systems for nuclear reactors. E. Long. To: U.K. Atomic Energy Authority.

Discharged fuel elements pass through a channel from a point above the reactor but inside the shielding to a remote point below the reactor outside the shielding, so that the shielding above the reactor retains its integrity and the risk of exposure is minimized, this risk being particularly serious in reactors using liquid sodium as a coolant.

B.P. 845,469. Nuclear reactors. J. A. W. Huggil. To: AEI-John Thompson Nuclear Energy Co., Ltd.

The flow of gas coolant through individual fuel channels is regulated by gags. When changing fuel elements the gag may be exposed to gas pressure without the counter pressure of the weight of the fuel elements. Furthermore, it may sometimes be necessary to remove the gag for exchange (variations of conditions). To comply with these requirements, the gag is held with latching means and a lifting member is connected to the gag through a lost motion coupling. This lost motion causes the latch to be disengaged before withdrawal.

B.P. 845,805. Nuclear reactor. To: Siemens-Schuckertwerke A.G. (Germany).

The moderator-containing components (e.g., heavy water) are separated from the cooling-medium-containing components (e.g., liquid potassium-sodium alloy) by a protective gas zone the pressure of which is raised by the cooling medium itself in a chamber through which the cooling medium flows into the active reactor region.

B.P. 845,913. Fuel elements for nuclear reactors. A. T. Bowden. To: C. A. Parsons and Co., Ltd.

The element is of the kind using solid fuel in a container sealed by end-closures welded to the container. In order to reduce stresses caused by differential expansion, closure members are welded into the protruding ends of the container with interlocking recesses so that closure member and container expand and contract together.

B.P. 846,330. Nuclear reactor fuel element. A. G. Robson. To: C. A. Parsons and Co., Ltd.

A fuel element, which can operate at 600°C and above, is composed of uranium oxide or uranium carbide, housed in a sealed container of aluminium oxide sintered in the temperature region of 1 000-1 500°C.

B.P. 846,497. Device for the detection of individual faulty fuel elements and the precise location of the position of the fracture on the surface of the faulty element. K. W. Cunningham, D. T. W. Alaiga-Kelley. To: Plessey Co., Ltd.

The device is based on the examination of uranium fuel elements in a neutron flux. A gas stream is directed over each fuel element and the activity of this stream is measured while the element is maintained in a neutron flux. The elements contained in one channel, e.g., may be transferred to a rotatable container within the biological shield to be tested sequentially.

B.P. 846,547. Thermonuclear reactor for producing fusion reaction. J. G. Linhart. To: British Thomson-Houston Co., Ltd.

Magnetic shock waves are applied to the ionized gas (hydrogen, deuterium, helium, tritium or mixtures) so as to compress the gas adiabatically.

B.P. 846,753. Heat insulation device. E. Long. To: U.K. Atomic Energy Authority.

In a liquid sodium-cooled graphite-moderated reactor using a form of re-entrant cooling, hot and cold liquids on top of the reactor core are contained in a tank divided by a horizontal diaphragm. Pipes pass from the upper tank to the lower tank through the diaphragm on which layers of steel tiles spaced from one another are provided to accommodate for thermal expansion. The tiles in any layer are arranged to overlap the tiles in adjacent layers.

B.P. 846,754. Heat exchangers. E. Long, R. J. Symes. To: U.K. Atomic Energy Authority.

A heat exchanger of the shell and tube type for primary and secondary liquid sodium. A removable heat exchanger unit comprises a nest of tubes which is arranged in a tube between upper and lower tanks for the primary liquid. A surrounding shell extends between tube plates for the second liquid which passes in counter-current through the nest of tubes.

B.P. 846,923. Nuclear reactor. D. M. Sutherland, P. R. Tipper. To: A.E.I.-John Thompson Nuclear Energy Co., Ltd.

A grab for loading and unloading fuel elements with claws rotatable about a vertical axis into and out of engagement with a fuel element carrier is operated by a pair of cables and pulleys so that equal movement of the two cables will raise or lower the grab while differential movement of the cables will rotate the claws.

B.P. 846,950. Heat exchangers especially applicable to the cooling of atomic piles. To: Soc. Nat. d'Etude et de Construction de Moteurs d'Aviation (France).

A heat exchanger, containing a bundle of tubes or tube groups, is operated with a pulsating flow. The motion is tuned to the natural frequency of the tubes and the phase of the pulsatory flow through each tube or group is so adjusted that it will be out-of-phase in relation to the pulses through the other tubes or groups. The differences in phase prevent vibration.

B.P. 846,977. Thermal insulation. W. G. Marskell, D. McNaughton. To: Babcock and Wilcox, Ltd.

Suitable for use within the pressure vessel of a gas-cooled nuclear reactor. It is preferably a hollow shallow metal case divided by partitioning walls into relatively small compartments filled with graphite of particulate form. The case is closed but permits fluid pressure eqalization inside and outside.

B.P. 846,996. Steam generating plant and method of generating steam. To: Babcock and Wilcox, Ltd.

If steam comes into direct contact with sodium or potassium the risk of an explosion reaction is much less than if water were present. Therefore a comparatively safe method of generating steam is to superheat steam by indirect heat transfer from the reactor-heated liquid metal and generate the steam by heat transfer between the superheated steam and water.

B.P. 847,079. Shock-absorbing device. H. H. Heath, R. H. Rout. To: English Electric Co., Ltd.

Two tubular telescopic sections held together by a shear pin carry a plunger projecting from one end. The plunger is provided with a multi-start thread which is stripped by a shoulder when moving a certain length through the shear pin breaking under excess load. The device is particularly useful for attachment to the lower end of a control rod.

B.P. 847,123. Cooling system for nuclear reactors. S. Fawcett. To: U.K. Atomic Energy Authority.

Two sets of coolant (nitrogen) paths are provided through the (graphite) moderator, one set in the vicinity of the fuel and the other set remote from the fuel. The coolant flow can be throttled so that the coolant in the fuel channels has a lower temperature than the coolant in the other channels.

B.P. 847,492. Electromagnetic interaction pumps suitable for liquid metals. D. A. Watt. To: U.K. Atomic Energy Authority.

A closed iron circuit carries a primary winding and a further iron circuit with an air gap is in shunt with part of the closed iron circuit. A secondary winding looping the shunted part feeds current through liquid metal in a duct in the air gap. Interaction between current and magnetic field in the air gap produces the pumping pressure.

B.P. 847,620. Radiation monitors. M. W. Jervis. To: A.E.I.-John Thompson Nuclear Energy Co., Ltd.

The monitor is continuously tested by a stepped voltage test pulse to produce an output pulse in the amplifier and indicator circuit due to the capacity effect of the ionization chamber.

Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

Xeroradiography In Industry

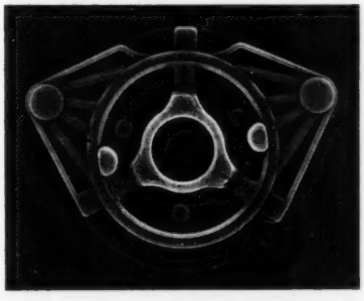
The application of xerography, or the production of a visible image by the adherence of a dry powder to an electrostatic image, to radiographic work, has several advantages for some classes of work, and xeroradiographic equipment is already commercially available. Briefly, the process uses a photoconductive plate, to which

Aluminium alloy casting specially designed with a wide range of thicknesses and defects.

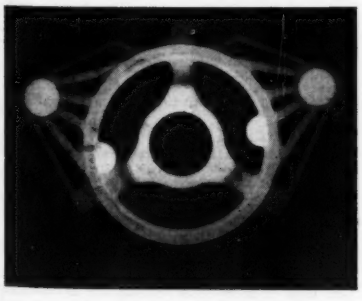
a positive electrostatic charge is applied, this being wholly or partially discharged by the X-ray image, leaving a latent electrostatic image, which is "developed" by applying a negatively charged powder, which adheres to a greater or lesser degree, according to the state of charge of the plate. The image may be examined within 30 sec of the X-ray exposure, and a photographic record made if desired; the plate may be re-used at least one thousand times.

In the Rank-Xerox equipment now being marketed, the plate used is of aluminium, with a coating of amorphous selenium; it is contained in a casette fitted with an aluminium dark slide and is sensitized by placing in a charging unit and withdrawing the dark slide. The charge is applied at 3 kV by means of a wire within the charge unit which lies close to the plate, and automatically traverses the whole of the area. The casette is then exposed with any normal type of X-ray unit, exposures being of the same order as for medium-speed industrial film. Placed in a developer unit, the plate surface is then sprayed with powder by a traversing air-brush unit. Examination takes place in a viewing unit, with diffused illumination to prevent unwanted reflection, and a built-in camera of the Leica type makes a permanent record. The plate is returned to the charging-cleaning unit for removal of the image, which is effected by a motor-driven brush of soft fur; after heavy exposures a "relaxing" process, consisting of a short heating and cooling cycle, may be necessary to remove all trace of latent image.

Xeroradiography gives a low "overall" contrast, thus enabling a wide range of thicknesses to be examined; at the same time, the local contrast is extremely high, making visible defects which might not be visible by normal methods, as can be seen from the accompanying illustrations of an aluminium casting specially prepared to contain a variety of defects. (Some allowance must be made for the limitations of half-tone reproduction).



Xeroradiograph of casting showing the greater range of detail to be observed.

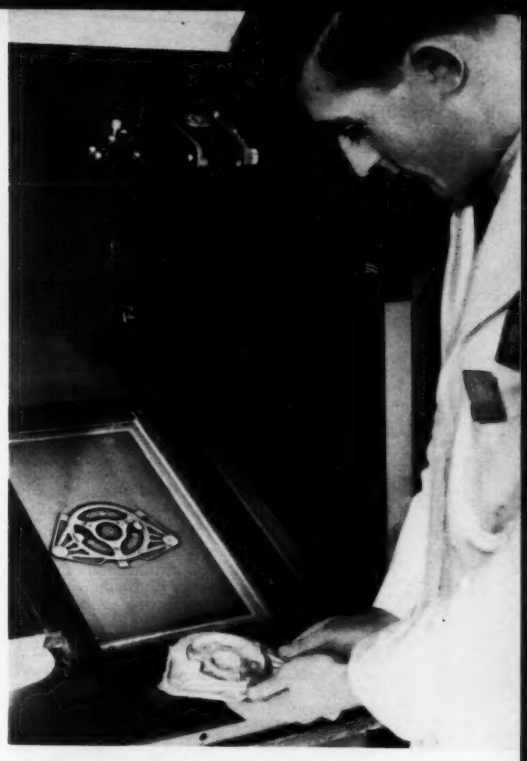


Normal X-ray of casting.

Applications for which the process would appear to be ideally suited include the rapid examination of trial castings prior to quantity production, and similar processes, where the rapidity of operation is of prime importance. In the nuclear field, it would seem to have possibilities in the inspection of fuel elements and similar items, also for a number of pressure parts and smaller components. The application to pressure vessel welds is not immediately envisaged, although the difficulties of producing plate and dark slide in flexible units (such as would be required for radiography of circumferential welds) are not, by any means, considered insuperable.

(Watson & Sons (Electro-Medical), Ltd., Industrial Division, East Lane, North Wembley, Middlesex.)

1083



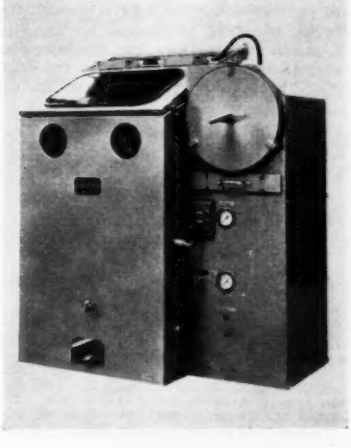
The Rank-Xerox viewing cabinet in use, showing the built-in camera for permanent records.

New Vacu-Blast Equipment

Intended for producing surface finishes by means of fine-mesh dry abrasives, the Vacu-Blast dry honer unit avoids the handling and drying associated with wet or slurry processes, while eliminating the "packing" that has often proved a barrier to the use of dry abrasives in grades as fine as 600 mesh, by means of feed aeration.

While it is possible to obtain an almost infinite variety of surface finish, by changing the particle size, uniformity is obtained by ensuring that the particle size remains constant, and all particles below the required size are removed, together with the deposits,

The Vacu-Blast dry honer unit.



by cyclonic action, and carried to the dust receptacle of the machine. The range of finishes obtainable varies from a fine matt surface, suitable for plating, to a relatively coarse etch suitable for, say, bonding to rubber.

The machine may be castor-mounted and readily moved from one department to another, since it requires only electrical and compressed air connections. Three models are available, with internal working spaces of 23 in × 23 in, 27 in × 27 in, and 30 in × 36 in, respectively.

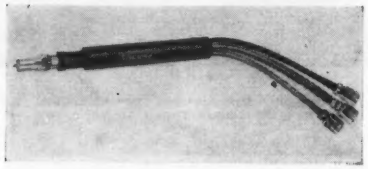
(Vacu-Blast Ltd., Wellcroft Road, Slough, Bucks.)

1084

Argon Welding Torches

A range of argon-arc welding equipment developed by the Tec Torch Company in the U.S. is now being marketed in Britain. Welding torches range from air-cooled hand units of 100 amp capacity to 350 amp models suitable for automatic machine welding.

A feature of the small unit is its light weight (3 oz) and small size (1 in diameter)



The Tec argon-arc welding torch.

making it suitable for use in confined spaces. A transparent " Vycor " nozzle shrouds the nozzle to within a short distance of the tip and, it is claimed, results in savings in argon consumption of up to 20%.

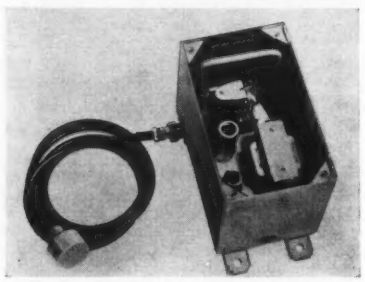
A further innovation is a spot-welding gun fed with argon, which is said to be capable of welding, from one side only, stainless steel, copper, brass, and a range of nickel alloys up to ¼ in thick to base material of any thickness; eight standard locators allow all types of joint—lap, butt, T, and corner welds—to be made.

(Interlas Ltd., 9 Church Street, Ampthill, Bedford.)

1085

Proximity Switch

Originally designed for use on machine tools (on which it has been widely applied over a period of five years) the type CE 32 proximity switch is now being made generally available for all applications requiring limit switches where the duty is particularly arduous, or where mechanical operation is not practicable. Operating on inductive coupling, the unit is not affected by stray pick-up, and has been used in the vicinity



Donovan CE32 proximity switch, with pick-up.

of high-power R.F. heating equipment without trouble.

The normal operating head is 1¼ in diameter, and may operate submerged, if required. Normal consumption is about 6 W; wide variation in supply voltage (230 or 400 V) does not affect the operation. The relay operates when a substantially flat metal surface of about the same area as the search coil (1·2 in²) approaches within, say, ¼ in, repetitive accuracy being of the order of 0·02 in.

(The Donovan Electrical Co., Ltd., Granville Street, Birmingham.)

1086

Disposable Gloves

Polythene gloves, originally developed for hospital work, to be used and thrown away are now being marketed under the name of " Portex " by a subsidiary company of the Smiths Motor Accessory Division. Ultralight, they are

"Portex" disposable polythene gloves.

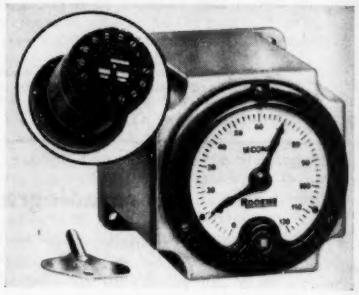
suitable for a number of purposes, including the handling of components where corrosion troubles might arise from the contact with the hand. They are packed in bags of 100 (50 pairs) and are internally dusted with talc for ease of fitting and removal.

(Portland Plastics Ltd., Knightsbridge House, 197 Knightsbridge, London, S.W.7.)

1087

Redesigned Timer

Redesign of the Rodene type 7000 synchronous timer unit has resulted in a number of detail improvements, as well as an increase in the range available. Amongst detail changes may be mentioned the use of new materials for contact operation and motor winding bobbin; the replacement of the friction drive—fitted to prevent damage



The new Rodene 7000 synchronous timer.

should the setting be altered while the timer is running—by a free-wheel arrangement, and new terminal arrangements which, amongst other things, allow the clutch terminals to be brought out separately. The clutch can, therefore, be operated by a separate d.c. supply, if required, to prevent unwanted resetting in the event of mains failure.

Either normally closed or normally open operation is possible, and the operating voltage can be as high as 440 V, if required, flush or projecting pattern, with fixed setting knob or removable key. The standard time

BRIEFLY . . .

C. A. Norgren Ltd., Shipston-on-Stour, Warwickshire, have developed a new filter-regulator unit for compressed-air systems. Manufactured for ¼ in and ⅜ in pipe, the units are available with transparent bowl for 150 psi, 120°F, or with metal bowl for 250 psi, 200°F. Filters range from 5 *μm* to 74 *μm*. **B241**

A new line of viscose filter tube units has been introduced by **Sethco Mfg. Corporation,** 2284 Babylon Turnpike, Merrick, Long Island, New York. Intended as a low-cost alternative to the existing range of cotton, dynel, porous stone and porous carbon filters, they are available with steel, stainless steel or polypropylene cores in filter densities of 25, 15 and 10 *μm* and are suitable for operation in solutions of 3—11 pH. **B242**

A new range of vibratory screens for sifting fine powders and slurries has been developed by the **Sinex Engineering Company,** North Feltham Trading Estate, Feltham, Middlesex. Standard sizes range from 4 ft x 3 ft to 10 ft x 4 ft. **B243**

Two new ElRemCo universal relays are announced by the **Electrical Remote Control Co., Ltd.,** of Bush Fair, Tye Green, Harlow New Town, Essex. Of the latching type, one model is hand reset, the other, electrically reset. Available up to 440 V a.c. or 230 V d.c. operation, the contact rating varies from 6 amp at 230 V, to 50 c/s to 1 amp at 240 V d.c. (non-inductive). Up to eight contact sets can be fitted. **B244**

Counting Instruments Ltd., 5 Elstree Way, Boreham Wood, Hertfordshire, announce their series 400 electromagnetic counter which is available with either mechanical or electrical reset. The four wheels carry 7/32 in (5.4 mm) figures; the overall dimensions of the counter are 2¾ in x 2 3/16 in x 2⅝ in. **B245**

New designs of cooling tower fans are announced by **The Airscrew Company and Jicwood Ltd.,** Weybridge, Surrey. Intended for induced-draught work, the designs incorporate complete protection from deterioration due to carry-over and splashing. Prototype tests have been carried out under continuous spray conditions. **B246**

A new type of solid state particle detector is announced by **Semi-Elements Inc.,** of Saxonburg Boulevard, Saxonburg, Pennsylvania. Alpha particles, protons and heavier particles can be detected; the energy level of alpha particles detected is in the range from 0.5 to 10MeV. Resolution is below 4%, and the signal-to-noise ratio is listed at 15—1, although a ratio as high as 50—1 is frequently obtained. **B247**

British Area Regulators, Ltd., of Sisson Road, Gloucester, announce that the Skinner series of solenoid valves has been recently extended to include a new 3-way valve, suitable for operation on hydraulic systems up to 1 000 psi. Other models are available for pressures up to 3 000 psi. The design is compact, with an equivalent bore of 3/32 in, and have stainless steel body and internals. They are available with explosion-proof housing, if desired. The coil consumption is 10W. **B248**

Electrolube, Ltd., 16 Berkeley Street, London, W.1, announce that their electrical lubricating fluid can now be obtained in aerosol dispensers, which can be fitted with 5 in extension nozzles, which are particularly convenient when treating brushes and commutators of small motors, switchgear, etc. **B249**

James H. Randall and Son, Ltd., Paddington Green Works, London, W.2, have increased their range of drawing filing cabinets to include a 30-drawer unit capable of filing " antiquarian " size (53 in x 31 in) without folding. Drawers are protected front and back to prevent loss or damage. **B250**

Band-type heating elements, which can be placed directly round a metal drum and secured with spring fasteners, for warming solid or semi-solid contents for easy removal, are announced by **Electrothermal Engineering, Ltd.,** 270 Neville Road, London, E.7. **B251**

A new vacuum dry box, capable of being operated at a pressure of 50 microns, with a leak rate of 1 micron/min has been developed by **Controlled Atmosphere Enclosure Mfg. Co.,** P.O. Box 3693, Jacksonville 6, Florida. It is equipped with low-permeability butyl gloves, and can be used by several persons simultaneously. **B252**

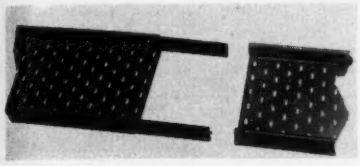
scales are ¼, 1, 4, 12, 36, 72 minutes and 3, 12, 24, 96 hours.

(D. Robinson and Co., Ltd., Gunnersbury House, 717 London Road, Hounslow, Middlesex.)

1088

Heavy-duty Cable Trays

Main feature of a new cable tray recently placed on the market is that the edges, instead of being plain right-angle bends, are



Greening RF 6 heavy-duty cable trays.

folded over into a narrow inverted "U" section, not only greatly strengthening the tray but facilitating neat joints between lengths by short connecting bars fitting within the turned-up section. Fewer perforations also strengthen the trays, known as the RF 6, and it is stated that they may safely be used as temporary access catwalks.

The RF 6 tray is manufactured in 8 ft lengths, in a variety of widths from 6 in to 24 in. A complete range of matching tees and bends is available.

(N. Greening and Sons, Ltd., P.O. Box 22 Britannia Works, Warrington, Lancashire.)

1089

Portable pH Meter

Developed in Austria (Ludwig Seibold) a new portable pH meter, now being marketed in this country, is little bigger than an electric torch, and can be easily carried about a plant to take readings anywhere, even with low depths of liquid.

The instrument, which

Seibold portable pH meter.

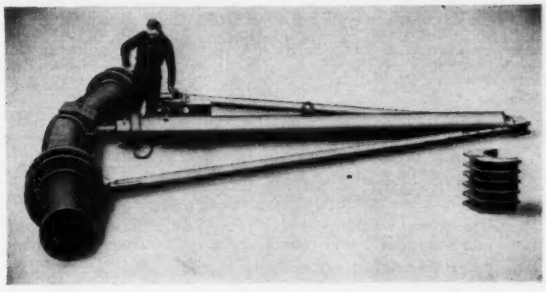
is 18½ in (470 mm) long, weighs less than 3½ lb, and is scaled from 2-12 pH, the normal accuracy being ±0·1 pH, although 0·05 pH accuracy can be obtained, if required. The mirror scale is 85 mm (3 11/32 in) long, scaled 0·2 pH per division. Operation is by a battery contained in the handle, and the circuit contains one subminiature electrometer triode. Calibration adjustment is fitted, as well as temperature adjustment, for ambient temperatures of 5–80°C.

(The H. G. Stevens Company, Ltd., 16 Coverdale Road, London, N.W.2.)

1090

Pipe Bending on Site

The "Staffa" range of bending machines now includes a portable unit capable of bending, on site, pipes up to 18 in o.d. × ¼ in wall thickness. To obtain portability, the normal bending head is replaced by a hydraulic thrust head, the pipe being restrained at the extremities of the bend by two pivoted arms carrying clamps to fit the pipe, the pivots being adjustable to increase the angle of bend.



Bending an 18 in pipe in the field with the new Staffa portable bender.

Power is provided by a simple air/hydraulic pump, operated (in the absence of a site air supply) by a small compressor. Relief valves are fitted to prevent overloading. It is stated that, with 18 in × ¼ in pipe, a 10° bend can be made in under 10 minutes.

(Chamberlain Industries Ltd., Staffa Works, Argall Avenue, Leyton, London, E.10.)

1091

New Alloy Steel

"Mar-aging," or the age-hardening of martensite by heat treatment is one of the essential features in a new type of nickel steel developed in the U.S. by the International Nickel Company, Inc.

With a composition of 18% Ni, 7% Co, 5% Mo, less than 0·5% titanium and a maximum carbon content of 0·05%, the material is said to achieve a yield strength higher than 250 000 psi, and a nil ductility temperature below −80°F; notch-tensile strength (notch radius 0·0005 in) exceeding 400 000 psi, and remarkable resistance to delayed cracking when exposed to corrosive atmosphere in a highly stressed condition. It is also stated that the alloy has unusually low work-hardening properties, thus permitting extensive cold forming, and is easily welded without preheating; full strength of the softened welded zone is easily restored by the mar-aging process, which consists in holding at 900°F for about 3 hours, and air cooling.

(The International Nickel Company (Mond), Ltd., Thames House, Millbank, London, S.W.1.)

1092

CATALOGUES

Green-Mercier hydro-pneumatic accumulators are described in a publication from **Fawcett Preston and Co., Ltd.,** Bromborough, Cheshire.

"Progress 60" is the title of a brochure from the Nuclear Division of **The Martin Company,** Baltimore 3, Maryland, describing some of the year's work on reactors, auxiliary power systems, direct energy conversion and fuel elements and materials development.

Complete project engineering and erection services and the facilities backing them are described in a brochure issued by the **Power Gas Corporation, Ltd.,** P.O. Box 21, Stockton-on-Tees.

From **L. A. Mitchell, Ltd.,** Harvester House, 37 Peter St., Manchester, 2, come lists of ceramic-lined diaphragm and centrifugal chemical pumps.

Bench assembly trays, storage bins and special industrial containers in moulded plastics are described in a leaflet received from **Kabi (Electrical and Plastics), Ltd.,** Cranborne Road, Potters Bar, Middx.

MS 4 silicone compound for potting, lubrication and sealing purposes is described in a leaflet issued by **Midland Silicones, Ltd.,** 68 Knightsbridge, London, S.W.1. Two other lists show suppliers and fabricators of Silastomer silicone rubber compounds.

Catalogues of complete equipment for vacuum technology, metal cutting plant and vacuum melting and casting plant manufactured by Geraetebau-Anstalt Balzers have been received from **Balzers High Vacuum, Ltd.,** 1 Mornington Terrace, London, N.W.1.

A comprehensive range of pH meters including industrial and portable types has been issued by **Electronic Instruments, Ltd.,** Richmond, Surrey.

An abridged version of the Detel Guide to protective coatings is available from **Detel Products, Ltd.,** Stonefield Way, South Ruislip, Middx.

The TBA steam turbopump is described in a leaflet received from **Pulsometer Engineering Co., Ltd.,** Nine Elms Works, Reading, Berks.

Thomas Industrial Automation, Ltd., Station Buildings, Altrincham, Cheshire, have issued a leaflet on the Leveltron multipoint automatic controller.

Examples of Plasmet printed circuits and hints on the design of lay-outs are described in leaflets received from **Printed Circuits, Ltd.,** Stirling Corner, Barnet By-pass, Borehamwood, Herts.

"Reylovolt" low voltage transformers, of dust-proof and weather-proof type, are described in leaflets received from the **Donovan Electrical Co., Ltd.,** Granville Street, Birmingham, 1.

The 1961 edition of "Abridged Valve Data," containing some 40 pp. of classified information, has been issued by the **English Electric Valve Co., Ltd.,** Chelmsford, Essex.

Sectional and prefabricated buildings are the subject of new leaflets from **J. E. Lesser and Sons, Ltd.,** Green Lane, Hounslow, Middlesex.

Transistorized cam pick-offs, intended to replace mechanical auxiliary switches in applications such as synchronization of high-speed machines, are described in a leaflet from **Servo Consultants, Ltd.,** 10 Bouverie Place, London, W.2.

X-Lon Products Ltd., 48 Gillingham Street, London, S.W.1, have published a 28-page catalogue of plastics laboratory equipment of all types, in polythene, polypropylene, p.v.c., p.t.f.e., acrylics and polystyrene.

The Harvey-Wells Nuclear Corporation, P.O. Box 189, Framingham, Mass., have sent leaflets describing laboratory electromagnets, fluxmeters and probes.

Vol. 1, No. 2, of *AEI Engineering* (33 Grosvenor Place, London, S.W.1) contains an article on the use of cadmium sulphide crystals for gamma-ray detection.

C. F. Casella and Co., Ltd., Regent House, Fitzroy Square, London, W.1, have issued a brochure celebrating their 150th anniversary.

N.V. Philips Gloeilampenfabrieken, Eindhoven, Holland, have issued the third edition of their abridged catalogue of nuclear equipment. This 41-page publication includes instruments of all types, portable neutron generators, lead castles, low-background assemblies, radioactive sources and isotopes, with references to the detailed publications available.

Technical Description No. 27, describing high torque, high slip and high reactance squirrel cage induction motors, has been issued by **The General Electric Co., Ltd.,** Erith, Kent.

Orbits . . .

COMPARISONS, said Shakespeare, "are odorous." "Comparisons," said Burton, John Donne and a few others, "are odious." "Comparisons," said Cervantes, "are offensive." "Comparisons," says Tangent, modestly putting himself at the tail end of this imposing list, "are ruddy nearly impossible."

If you disagree, just try answering one simple question: Which is the most economical type of reactor? Never mind about running costs for the moment, just let's concentrate on the cost of putting up the station. On page 216 you will find a brief summary of a report prepared by a number of stout-hearted types in the U.S.AEC, which gives, amongst other information, the total costs of stations obtained from all over the world (except such inaccessible spots as the U.S.S.R. and Dounreay) to tabulate the cost per kilowatt. The headaches afflicting the authors of this remarkable piece of work may be judged from the footnotes, which are nearly as bulky as the tables themselves, but they are as nothing to those which threaten anyone rash enough to draw hasty conclusions therefrom.

It is not fair to base our arguments on very small plants; it is equally unfair to select reactors which are frankly experimental. If we cut out these, we find that some of the plants that we'd like to compare are still little more than twinkles in the eye of their designers (if designers ever do twinkle). Dresden is the lowest figure shown on the chart, with Dungeness as a runner-up. (Sizewell might have beaten it, but the footnote introduces an element of doubt as to the basis of comparison.) Figures can prove anything, they say. Our modest bob is still on the gas-cooled reactor—providing that performance is not emphasised at the expense of everything else.

Cheap and Cheerful

In our opinion—and who cares a sausage for our opinion, anyway—the formula for success in power station work *at present* lies not in going flat out for high efficiency, but in cutting capital costs by trimming frills right out; by looking hard at everything, and seeing whether this bit really has to be made to half-thou limits and whether that bit really has to have an impurity level of 1 ppm or less. In trying to produce the sort of thing, in fact, that is referred to in other spheres of existence as Commercial Grade, or Domestic Blend, or even Family Model.

Note the qualifying "at present." Development activity we must have. Let not our attitude be that of the hill-billy storekeeper who vowed that he . . . "weren't gonna stock no dratted television sets till he cleared that shelf full of magic-lantern slides." That way lies stagnation. But there is still much to be done with the natural U reactor, in the form of (horrid but expressive word) "streamlining."

Polylateral Charging

Cost reduction in the Sizewell design, by combining the two charge faces, has already been noted, and a suggestion has been made by a colleague that this objective should be pursued several stages further. If reactors were built with horizontal channels, he points out, it would be possible to arrange four reactors around a single charge machine, by adopting a square formation; six, if a hexagon. In fact, by adding two vertical-channel reactors with top and bottom charging respectively, it would be possible to service a group of eight reactors with a single charge machine. The objection that the machine might be difficult of access for maintenance was met by the bland rejoinder that there wouldn't be time for it, anyway.

Spot On . . .

Neglecting hook swing, how closely could you align an ordinary gantry crane over a given spot? With one of the elderly models, which jumps as if it had been stung on the first notch of either cross traverse or long travel, and reluctantly comes to rest, weaving and clanking, when the brakes are applied, a final positioning within six inches would be either good luck or exceedingly good driving. Since, in principle, a charge/discharge machine is really a specialized form of a gantry crane, we looked a bit sideways when told that the AGR machine would locate itself to within 5 thou. of a given standpipe, because it weighs 400 tons and there's a fair amount of gearing in both movements, just to ensure that nothing is too simple.

Nevertheless, we came away from having a look at it with different ideas. Neither John Brown (SEND) who designed it, nor their subsidiary, Markham and Co., who built it, was exactly talkative about it (whoever is about anything interesting?). We gathered however, that the control servos on both movements are so sensitive (the final approach speed is only a few thou. a minute) and the constructional tolerances are so tight, that the specified 5 thou. give it room to slop about in.

. . . But Why?

Sincerely as we admire the skill and determination shown by those responsible, we can't help wondering why the snout sealing arrangements couldn't have incorporated a little flexibility, to make such accuracy unnecessary. Ever since Calder, engineers have been performing minor miracles, until it is now taken for granted that however fantastic the requirement, someone will be found to do it. So they will . . . at a price. No one, naturally, would say how much the machine had cost, but if there was much change left out of three-fifty kiloquid (or, say, a megabuck), at a rough guess, then Tangent is a Dutchman . . . *Dank U wel, Mijnheer de Voorzitter, Dames en Heren* . . . just practising; we could be wrong.

Ornithological Outburst

Just received from the Benson-Lehner Corporation, a copy of a book entitled "Strictly Birdmanship, or How to Lay the Egg that Kills the Golden Goose," a more-than-somewhat off-beat comment on the relationship between government and industry in the U.S. research and development field. The tone can be gathered by quoting just one UPTKIA (Useful Ploys to Keep Industry Alert) where a very fierce-looking American Eagle is saying, to a worried-looking bespectacled duck . . . "But you don't seem to understand, Dr. Smith—the very fact that it took two years to negotiate the contract is the reason why you *must* complete the development in six months. You wouldn't want to be responsible for stifling progress, would you?"

The author, Bernard Benson, was born in England, and is ex-R.A.F. He is also, for our money, one who has lost his childhood belief in fairies. We think his faith in Santa Claus is a bit shaky, too. The general reaction to the book is to wipe one's eyes and say . . . "Thank Heaven it can't happen here." Which is always good for another laugh.

MTS Units

The Waverley Gold Medal Essay Competition, value £100, is being sponsored, for the ninth year in succession, by the journal *Research*.

The avowed object of the competition is . . . "to encourage scientists to write clearly and comprehensively about their work. . ." What a pity that *Research* did not add the magic words . . . "and promptly," thus painlessly introducing them to the mysteries of MTS (Middle Time Scale) units.

Bitter experience has shown us that, as a body, scientists have no middle time scale. Talk to them about millimicroseconds, and they are right on the ball; speak of decay times of 10^3 years, and they are still on familiar ground. But ask for something by Tuesday week and they (or most of them) are completely clueless and, when cornered, are apt to lecture one on the fallacy of regarding time as a dimension, anyway . . . Boy! My tranquillizers!!

Tail Piece

Only a very short one this time, chums. It would be nice to be topical but it can't always be managed. However, the two items—the Parliamentary token vote for the Ministry of Transport's nuclear ship and the appointment of the deputy chairman of the AEA—although pretty whiskery by now, seemed to hang together. . . .

At present two questions are going the rounds
We can't see the answers (if any)
What Marples will do with his meagre ten pounds
The AEA do with their Penney?

Tangent